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NORTHWEST SCIENCE

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Announcements

Annual Spring Meeting

Greetings!

Remember, March 22-26 is the 1988 meeting of the Northwest Scientific Association! The folks at Southern Oregon State have worked hard to stage a successful annual meeting. Please note the *two* symposia, plus three special field trips.

The first symposium is Wednesday, March 23, 1988, sponsored by the Forestry Intensified Research (FIR) Project, Oregon State University College of Forestry, and the theme is "Reforestation Research Advances in Southwest Oregon."

The second symposium (to be held on Friday, March 25) is sponsored by the USDA Forest Service, Southwest Oregon Ecology Program. Tom Atzet (Area Ecologist, Siskiyou National Forest) and Dave Wheeler are the planners in charge of this symposium.

Contributed papers are scheduled for Thursday and Friday, March 24-25.

Botany Field Trip. The Thursday field trip sponsored by the Botany Department has been changed from "Agate Desert and Lower Table Rock" to "Eight Dollar Mountain, Darlingtonia Bog" in the Siskiyou Mountains, and will be led by Dr. Frank Lang, Professor of Botany at Southern Oregon State College.

Geology Field Trip. The Geology field trip on Friday is to the "Siskiyou Mountains, Klamath River Canyon" and Dr. Jad D'Allura, Geology Department at Southern Oregon State College, is the leader.

Biology Field Trip. Dr. John Sullivan, Professor of Biology at Southern Oregon State College will provide an opportunity on Saturday to visit the "Klamath Lake/Tule Lake Wildlife Refuge" to view a variety of waterfowl and birds of prey.

By now you should have received a packet of information that includes the subjects of the symposia, field trips, lodging information, and parking information/requests. Confirmation of your registration will be sent to you shortly after we receive it.

Reservations for lodging should be made early since the Shakespearean Festival will be presenting their spring program. (If you are interested in tickets and information on the Oregon Shakespearean Festival presentations, call [503] 482-4331, or write to Festival Box Office, P.O. Box 158, Ashland, OR 97520.)

See you in March!

John O. Sullivan
Claude W. Curran
Program Coordinators

John R. Lacey, Steven B. Laursen, Jack C. Gilchrist, Roger M. Brownson, Jan Anzick, and **Stuart Doggett**[1]
Montana State University, Cooperative Extension Service, Bozeman, Montana 59717

Economic and Social Implications of Managing Wildlife on Private Land in Montana

Abstract

A study was conducted in Montana to evaluate the potential for wildlife and public recreation on private lands. This is to be used to formulate public policy that benefits wildlife and fishery resources. Data were obtained through a mail survey in 1986 of 526 members of the Montana Stockgrowers Association. Ninety percent of the respondents felt they should be reimbursed for providing recreational activities on private land. Eight percent were presently charging access fees on their land. Fifty-seven percent of the landowners charging access fees had invested in habitat improvement practices. Only 8% of landowners who did not lease to sportsmen were aware of improvement projects being done for the benefit of wildlife habitat. Results indicate: 1) an increase in number of private landowners implementing recreation enterprises on their land, 2) landowners who charge access fees tend to invest more in habitat and management practices, and 3) a need for agencies to further develop management strategies that provide landowners with economic incentives to improve wildlife habitat. Results of this survey should improve communication between landowners, sportsmen, and wildlife biologists.

Introduction

Wildlife populations are threatened by an increasing human population that converts rural land to urban uses, removes fencerows, transforms small farms to large corporations and applies intensive agricultural practices on wetlands and steephills (Poelker and Buss 1972, Gottschalk 1977, and Pineo 1985). Although the importance of habitat quality and quantity is recognized (Alexander and Kellert 1984), managing habitat for the benefit of wildlife is mostly without economic incentive. Two-thirds of the nation's wildlife and fisheries habitat is on private lands (USDA Extension Service 1986). More than 60 percent of all hunting, fishing, trapping and other related wildlife activities take place on these lands. In Montana, 75 percent of the grazable woodland and range is privately owned (Montana Department of Natural Resources and Conservation 1977).

Owners of private land can obtain assistance in clarifying and achieving their objectives for managing wildlife resources and improving habitat from the Cooperative Extension Service (USDA Extension Service 1986). Land management agencies encourage voluntary conservation practices, and provide financial incentives and technical assistance for improving habitat (Alexander and Kellert 1984). Despite these programs, management of wildlife populations is not an important economic consideration on most private land. Some landowners recognize that big game animals compete with livestock for forage, trample forage and wet soils, and damage crops and fences. Others deny hunter access to private lands because they perceive the potential for intentional and unintentional vandalism (to roads, fences, and other facilities), spread of noxious weeds, and fear their susceptibility to liability claims.

Property rights in wildlife differ from those defined for domestic animals such as dogs, cattle, and sheep (Kramer 1982). Wild animals are those animals wild by nature, which, because of habit, mode of life, or natural instinct, are incapable of being completely domesticated. With the exception of animals located on lands within the National Park System, the United States usually does not assert ownership in game animals within the various states (Kramer 1982). However, the courts have supported the need for states to regulate the protection, conservation, and the taking of game animals within their borders. Thus, while game animals are not subject to any type of public ownership, they remain under state and federal governmental regulation and control. Generally, there is no property right in wild animals until they have been reduced to lawful possession. Accordingly, to obtain private

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ownership in game animals, one must have them within his actual possession, custody, or control, and this he may do by hunting, taming, domesticating, or confining them in compliance with state and federal law (Kramer 1982).

Property right in a game animal is not determined by its habitat. A landowner does not own the game animals which inhabit his land. However, they do own the exclusive right to hunt them, subject to the right of the state to prohibit or regulate such hunting. Because of this exclusive right of landowners, a state cannot authorize one to enter another's premises for the purpose of hunting without first obtaining the landowner's permission, nor does the possession of a hunting license allow a hunter to enter private property without the landowner's permission. However, a landowner may convey hunting rights to another by the granting or leasing of his property for such purposes (Kramer 1982).

Income has been generated from wildlife on federal lands through the packers, outfitters, and guides and on private lands through both nonconsumptive use and hunting rights. The practice of charging access fees for hunting is common in Texas, where hunters paid private landowners $200,000,000 in 1983. It is less common in states like Montana where federal land management agencies control much of the land (Thomas 1984).

Fee hunting has become an issue in Montana because landowners and sportsmen have differing opinions on legality and ramifications of such activity (Hadley and Carroll 1986). While most landowners desire compensation for providing wildlife habitat and recreational opportunities, sportsmen feel that game animals are a public resource managed through license fees paid by sportsmen's dollars (Hadley and Carroll 1986). Many do not want to pay, through a fee hunting system, for something they already support financially.

The overall objective of this study was to gain a better understanding of the characteristics of fee hunting and other recreational enterprises on private land in Montana and obtain information that will assist private landowners in evaluating multiple-use management alternatives for their land and water. Results have implications for the management of wildlife habitat and populations on private lands. They can be useful in 1) predicting the future of fee hunting, 2) evaluating current programs of landowner assistance, 3) examining the potential impact of fee hunting on wildlife, 4) improving communication and understanding between landowners, sportsmen, and wildlife biologists, and 5) providing data to aid policymakers.

Methods

In April 1986 a self-administered, mail-back questionnaire (Dillman 1978) was mailed to a random sample of 1,000 members of the Montana Stockgrowers Association. Two weeks later, a second copy of the questionnaire was sent to landowners who had not responded to the first mailing. The stockgrowers are a statewide organization of cattle producers and woolgrowers. They are a diverse group in terms of the number of livestock and the amount of land owned. While some operations consist entirely of private land, others include large acreages of federal land managed by the U.S. Forest Service and the Bureau of Land Management. The stockgrowers were logical cooperators in the study because their rangelands provide habitat for most of the wildlife species that are hunted in Montana.

The questionnaire was designed to collect information on how wildlife values are harvested and how wildlife considerations are incorporated into land management decisions. Specific issues included the popularity and extent of leasing, the characteristics of leasing operations, the number of big game animals on leased lands, whether habitat improvements are being implemented to benefit wildlife, what fees are charged, the economic potential of leasing land to sportsmen, and whether landowners should be reimbursed for providing opportunities to sportsmen. It was felt that this type of information would be useful in developing a strategy to anticipate and alleviate conflicts between landowners, sportsmen, and wildlife management agencies.

Frequency analyses were used to determine how respondents answered each question. In order to compare geographical differences in landowner response, the state was divided into five regions (Figure 1). These regions approximate the resource boundaries that the U.S. Soil Conservation Service uses. Chi-square analyses were used to determine if landowner response differed among regions or between landowners

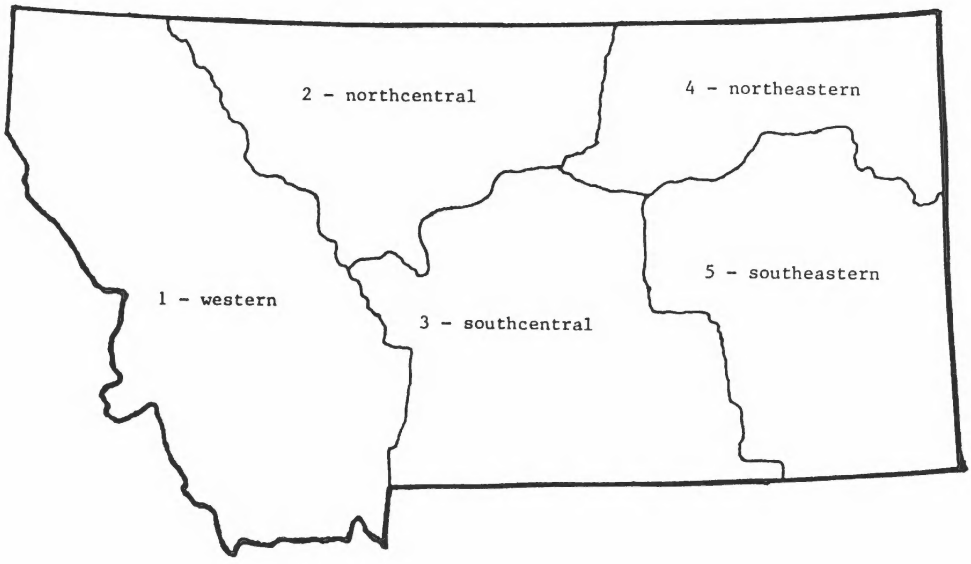

Figure 1. Map of Montana showing five geographic regions used in the 1985 landowner-sportsmen survey (1-western; 2-northcentral; 3-southcentral; 4-northeastern and 5-southeastern).

who do and do not lease land to sportsmen. The probability level was set at 5% (0.05) for all tests. A study of nonrespondents was not undertaken and no evaluation of nonresponse bias is offered.

Results and Discussion

Characteristics of Landowner Sportsmen Leases

A total of 555 questionnaires was returned (55 percent response rate). Twenty-nine questionnaires were omitted from the analysis because the respondent either reported no knowledge of access fees being charged or felt that their operation was atypical because of its location on an Indian Reservation.

Eight percent of the respondents leased land to sportsmen, but the percentage differed among the five regions ($P < .05$). The percentage of respondent lessors ranged from 14 percent in the southcentral to 2 percent in the northeastern region (Table 1).

Regional differences in numbers of landowners leasing land to sportsmen can be explained by pattern of land ownership and physical land characteristics. Leasing was uncommon in the western region where 33 percent of the total land was privately owned, but it was more common in the southcentral and southeastern regions where 66-76 percent of the land was privately owned (Table 1). In addition, most of the private land was located in relatively large units that made it possible for owners to charge access (only 5-14 percent of the private land was intermingled with public lands). Because of the small amount of public land in the latter regions, recreationists may be more willing to pay access fees for the use of private land.

The small amount of leasing activity in the northcentral region may be influenced by land use patterns. Cropland makes up 45 percent of the total acreage in this region, while the statewide average is 35 percent. As a result, there is probably less big game habitat; and consequently, big game hunters may be less interested in leasing private land.

The percentage of respondents leasing to sportsmen increased from 5 percent in 1975 to 8 percent in 1985. However, the percentage of lessors leasing more than one-half of their land increased from 15 percent in 1975 to 69 percent in 1985 (Figure 2). This suggests that lessors increased their leasing activity during the ten year period.

TABLE 1. Number of respondents and land area (and percent of total within region) by ownership class per geographic region, landowner sportsmen survey, 1986.

Region	Number of Respondents	Percent of Respondents Leasing Land to Sportsmen	Area of Land (hectares)			
			Private	Checkered[a]	Public	Total
Western	156	7	3,339,008	67,419	5,637,085	11,028,970
			(30.3%)	(18.5%)	(51.2%)	(100%)
Northcentral	83	4	4,430,405	489,247	1,382,019	6,324,670
			(70%)	(8%)	(22%)	(100%)
Southcentral	183	14	4,911,289	807,049	211,380	8,103,941
			(60.6%)	(13.3%)	(26.1%)	(100%)
Northeastern	53	2	2,107,526	867,682	1,693,548	4,679,210
			(45%)	(18.9%)	(36.1%)	(100%)
Southeastern	51	6	4,700,118	2,028,076	731,780	7,508,063
			(62.6%)	(27.6%)	(9.8%)	(100%)
Total	526	33	19,488,346	4,869,473	9,655,812	37,644,854

[a]Alternating tracts of land are under private and government ownership.

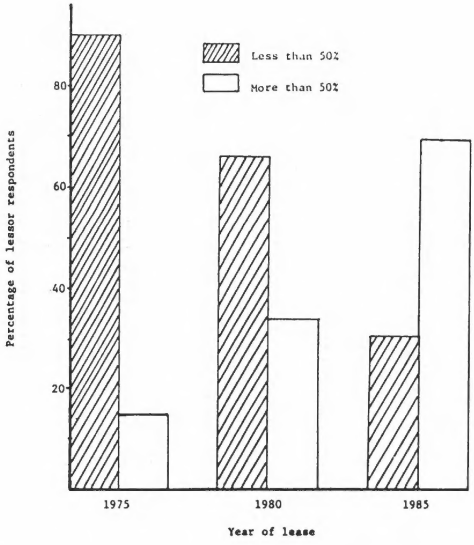

Figure 2. Percentage of lessor respondents' land that was leased to sportsmen.

Elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), whitetail deer (*Odocoileus virginianus*), and antelope (*Antilocapra americana*) were reported on the private land being leased to sportsmen. Although most landowners did not report the occurrence of all four species, most did report the presence of two or three. Herd sizes ranged from 150 whitetail deer to 225 mule deer (Table 2).

Grazing animals are specialized to some degree in their dietary needs or their feeding niches. They differ in the structure and physiology of their gastro-intestinal systems, in the micro-organisms which inhabit those systems, and in their abilities to break down or tolerate the protective chemical compounds which plants synthesize (Wagner 1976). Thus, each animal species feeds on only a portion of the total vegetation available to it. Cattle are known as grazers, but will take some browse. Deer are stereotyped as browsers, but also eat substantial amounts of forbs in summer and some grass during spring. Elk are among the most broad-spectrum feeders, but tend to be grazers on Montana's ranges. Although competition takes place only where the resource is used to the point of being in short supply, and the grazing animals are affected as a result, estimated forage consumption was computed as a function of number of animals, numbers of months spent on private land and animal weight (Table 2). Thus, 155 antelope for 8.5 months and 160 elk for 6 months would annually consume 264 and 576 animal unit months

TABLE 2. Estimated big game populations on ranches where landowners charge access fees.

Kind	Number of Ranches	Estimated Average Number of Animals[a]	Estimated Average Number of Months on Ranch[b]	AU[c]	AUMs[d]
Elk	30	160	6.0	.6	576
Mule Deer	34	225	9.1	.2	410
Whitetail Deer	30	150	8.9	.2	267
Antelope	31	155	8.5	.2	264

[a]Average number of animals estimated by the survey respondents.
[b]Average number of months that the big game animals spend on the private land estimated by the survey respondents.
[c]AU or animal unit is considered to be one mature (1000 lb.) cow or the equivalent based upon average daily forage consumption of 26 lbs. dry matter per day.
[d]AUM or animal unit month is the amount of feed or forage required by an animal unit for one month.

(AUMs), respectively. When elk and mule deer occurred on the same land, an average of 986 AUMs were consumed. This is the equivalent of forage needed to run 82 cows for one full year.

Most of the respondents leasing land to sportsmen reported that the total fee for providing elk hunting opportunities ranged from $1,000 to $2,000. Two landowners reported that they charge less than $100. Higher fees were associated with opportunities that lasted at least six days and included the use of a cabin and horses.

Fees charged for providing deer and antelope hunting opportunities ranged from $10 to $2,000. The lower fee was for a one-day hunt, while the higher fee bought a week-long opportunity that included the use of a cabin and horses.

Several landowners leased land to outfitters. The annual price for leases varied from $.75 to $1.00 per acre. Others reported that they received 10 percent of the outfitter's gross income. In either case, it was the outfitter's responsibility to regulate all hunting activities.

Income earned in 1985 by charging fees to sportsmen usually made up less than 5 percent of the lessor's total annual income. However, 8 percent of the lessors reported that leases to sportsmen accounted for more than 15 percent of their total earnings (Figure 3).

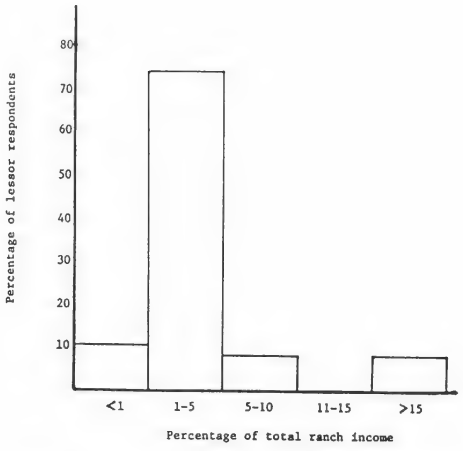

Figure 3. Income earned from leasing to sportsmen as percentage of total gross income for 1985.

Most of the leases between landowners and sportsmen involved single hunters (35%) or outfitters (33%). Cooperation with outfitters was significantly higher ($P < .05$) in southcentral Montana (41%) than in the other regions (23%). Hunting groups or clubs accounted for 25 percent of the leases. The remainder were with fishermen, birdwatchers, and others.

The vast majority of the hunting leases (83%) was granted by individual landowners. The percentage of leases in southcentral Montana involving cooperative agreements among a group of landowners (11%) was significantly higher ($P < .05$) than the percentage reported for the other regions (5%).

The terms of landowner-sportsmen leases have not been well defined in the past. Forty-five percent of the respondents reported that their leases were always informal and 34 percent used both written and informal lease agreements. Only 21 percent regularly used written agreements. Although the apparent reluctance of landowners to use formal lease agreements minimizes the involvement of attorneys, it may be detrimental to the landowner's long-term interests. An educational effort providing a number of model leases, with an analysis of the impact that they might have, may be appropriate.

Sixty-one percent of the leases were for a specific hunting season, while 22 percent were for one complete year. Twelve percent of the

leases were in effect until a specified number of animals were harvested. Only 5 percent of the leases covered more than one year. The predominance of short-term leases between landowners and sportsmen may be a reflection of an immature industry.

Eighty-seven percent of the landowners leasing land to sportsmen reported that they had liability insurance. The coverage include personal insurance (44%), outfitters insurance (41%) or both (15%). A higher percentage of the 13 percent that did not have liability insurance lived in the northcentral, northeastern and western regions.

Landowner Attitudes Regarding Sportsmen Leases

Elk and mule deer were rated by landowners as the two species with the greatest potential for economic return. While landowners in the western and southcentral regions rated elk as the potentially most valuable species, respondents in the southeastern and northeastern areas, where elk populations are very small and localized, gave elk a low rating. Thus, on a statewide basis, mule deer reportedly have the highest economic potential (Table 3).

TABLE 3. Perceived economic potential of wildlife by landowners who charge access fees.

	PERCENT OF RESPONDENTS[a]		
Kind	Very Important	Fairly Important	Unimportant
Elk	74	7	19
Mule Deer	97	0	3
Whitetail Deer	78	13	9
Antelope	58	31	11
Gallinaceous birds	25	68	7
Waterfowl	33	36	31
Fish	19	71	10

[a]Adjusted for missing values.

Thirty-three, 25 and 19 percent of the respondents gave waterfowl, gallinaceous birds and fish (*Pisces spp.*), respectively, a very high rating for economic potential (Table 3). Although this indicates that many of the respondents were cognizant of income potential of nonbig game species, the demand for, and ability of, private lands to supply opportunities to fish from blue ribbon trout streams and hunt waterfowl on prime wetlands in Montana has not been evaluated.

Fifty-seven percent of the lessor landowners reported that they used management practices to improve habitat on land leased to sportsmen. Forty percent of these landowners reported the use of more than one practice. The most common improvements were water developments and modification of range and forest management practices. Although some of these practices were implemented primarily to enhance livestock or timber production, with secondary benefits for wildlife, 14 percent of these landowners established food and/or cover plantings or manipulated wetlands. These improvements provided primary benefits for wildlife and suggest that many landowners recognize the value of wildlife.

Most respondents reported that landowners usually pay for habitat improvements on land that is leased to sportsmen. Others reported that the improvements were paid by sportsmen, government or cooperatively between sportsmen and landowners. Although the effect of economic incentives on landowner investment in wildlife habitat improvement cannot be directly assessed by data from the present study, the provision of economic incentives are a positive factor in Texas (Burger and Teer 1981). Inputs of resources for wildlife production are far less than inputs invested for production of livestock or other primary uses of the land. Many ranchers plan their range livestock programs to include wildlife considerations. The effects of many practices on livestock and wildlife are synergistic. One example would be the use of livestock to maintain vegetation succession in lower seral stages for the benefit of a species of wildlife.

Only 8 percent of the landowners who did not lease to sportsmen indicated that they were aware of any wildlife habitat improvement projects done on land leased to sportsmen. Educational programs that encourage sound stewardship and the implementation of wildlife habitat improvement programs are certainly justified for this group of landowners. Information regarding incentives for improving wildlife habitat should be an integral part of this educational effort.

Thirty-nine percent of the respondents reported that a certain number of hectares was

needed to develop and maintain opportunities for sportsmen, while the remaining 61 percent felt that the opportunities were not restricted by a minimum amount of land. Most of the former respondents felt that more than 2020 ha (5,000 ac) were needed for elk, 202-404 ha (500-1,000 ac) for mule deer, and less than 202 ha (500 ac) for whitetail deer, pheasant, grouse or fishing. There were no significant differences in the perception of a minimum area requirement among sample regions.

Eighty-seven percent of the respondents did not know of any legal problems between landowners and sportsmen and/or state agencies as a result of leasing land to sportsmen. Of the 13 percent who had heard of legal problems, most were related to the public's right to access along streams crossing private land. There were no significant differences in number of legal problems among regions.

Perceptions regarding the impact of leasing on outdoor opportunities differed significantly ($P < .05$) between the landowners who leased land to sportsmen and those who did not. Fifteen percent of the lessors felt that leasing would result in "many more" opportunities and 5 percent felt there would be "many less" opportunities. Corresponding figures for the nonlessors were 6 percent and 11 percent, respectively. The remaining landowners felt that opportunities for recreation would increase or decrease slightly, or not be affected by charging access fees.

Sixty percent of all respondents felt that leasing would not impact wildlife numbers. There were no significant differences in perception regarding the impact of leasing on wildlife populations between landowners who leased land to sportsmen and those who did not. However, a higher percentage of lessors (34%) than nonlessors (18%) expected overall habitat to improve with leasing.

Fifty-three percent of all respondents felt that the amount of private land being leased to sportsmen was of little importance in terms of total hunting opportunities. Thirty-five percent felt they were of some importance, while 12 percent felt they were of major importance. Regional differences were significant ($P < .05$). The percentage of respondents who felt the influence of private land was unimportant was 39 percent in southcentral and southeastern regions, and 65 percent in the western, northcentral and northeastern regions. Respondents reported that low wildlife numbers, intermingled public land, high proportion of government land in the region and limited ranch size were factors limiting the potential importance of private land on total hunting opportunities. No significant differences in reasons were found among regions.

Ninety percent of all respondents felt that landowners should be reimbursed for providing opportunities to sportsmen. This attitude was significantly ($P < .05$) more prevalent in southcentral and southeastern Montana than in the remaining three regions. Fifty-four percent of the respondents felt they should be reimbursed directly by sportsmen, 16 percent felt that they should be reimbursed by the state and 14% preferred receiving indirect benefits (e.g., tax breaks). Many operators may not view tax benefits as a positive incentive because they are losing money in their current agricultural operations. Some Montana landowners have expressed concern over using tax breaks (Pers. Comm.). In their opinion, it can be difficult to repeal tax legislation if it is found to be unsuitable, especially in states where the legislature meets once every two years. Fourteen percent of the respondents preferred a combination of two or more methods of reimbursement.

Comments written by respondents on the questionnaires indicated that the need to supplement traditional agricultural income was responsible for most of the increased interest in managing wildlife resources on private land. Another motivating factor was a backlash resulting from landowners' perception that there has been an erosion of individual rights (i.e., the replacement of "private-property rights" by new "public rights" including recreational opportunities, scenic-site access, and erosion control). As long as these factors persist, the number of landowners charging for access is expected to increase.

Existing Landowner-Sportsmen Programs

Special programs to encourage recreational access on private land have been developed in Montana, Oregon, and Washington, but not in Idaho (R. Clough Pers. Comm.). An example of state agency efforts is the block grant and walk-in program administered by Montana's Department of Fish, Wildlife and Parks (FW&P). While the

landowner permits hunter access to specific areas, department personnel provide signs and maps of the area, and patrol the land for compliance. At present, FW&P reports that there are more landowners willing to participate than funding allows, and more than 242,400 ha (600,000 ac) of private land has been entered into the program. However, this type of program does not provide the economic incentive for private landowners to improve wildlife habitat. The need for habitat management on private land (Poelker and Buss 1972, Gottschalk 1977, and Pineo 1985) and the comments from respondents in the present survey, indicate that alternative programs need to be evaluated in Montana.

Special legislation was enacted in California to encourage wildlife management on private land (California, Department of Fish and Game, 1985). Landowners work cooperatively with the Department to develop and implement wildlife management plans. The results of the plans are monitored and as the designated wildlife species responds, the landowners are rewarded with a certain number of hunting permits which can be used or sold at their discretion. Preliminary results suggest that landowners are enthusiastic about the program, and the general public is satisfied that big game numbers are increasing and more "total" hunting opportunities are available. According to the California Department of Fish and Game (1985), wildlife habitat on private land is improving. Colorado has also enacted specific programs to encourage habitat management on private lands.

Not only does the California experience suggest that it may be time to evaluate current wildlife management programs on private land in the Pacific Northwest, but the merits of fee hunting on public land has been advocated by the Public Land Law Review Commission, National Research Council and officials within the U.S. Department of Agriculture (Thomas 1984). Thomas suggested that fee hunting on public lands would be more acceptable if 25 percent of the fees were distributed to counties, 25 percent to states, 25 percent to habitat improvement, and the remainder to the federal treasury. In his effort to stimulate consideration, Thomas reported that the Sikes Act of 1974 provides the states with the opportunity to take the lead in prescribing fees for hunting on federal lands. Such fees are presently charged by Virginia, West Virginia, and Arizona.

Conclusions

The present survey indicated that 8 percent of survey respondents charged access fees for providing recreational activities on private land, but 90 percent of the respondents felt that they should be reimbursed for providing these opportunities. Because of the concern about the low-level of wildlife management on private lands, and the probability of increasing demand on the nation's wildlife resources, it is appropriate to further discuss management strategies that provide landowners with economic incentives to improve wildlife habitat. Furthermore, an educational effort is clearly needed to encourage sound stewardship and improvement of wildlife habitat on private lands. This consideration is supported by the present survey which indicates that landowners who charge access fees tend to invest more in habitat improvement practices.

Acknowledgements

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Tumtum Mountain, a late Pleistocene Volcanic Dome in Southwestern Washington

Abstract

Tumtum Mountain, a small, symmetrical, conical mountain rising 427 m above the east end of Chelatchie Prairie some 32 km southwest of Mt. St. Helens, has been described as a volcanic cone extruded along a fault zone, and as a Tertiary intrusive body exposed by erosion.

Recent studies have demonstrated that the mountain is a dome-like dacite extrusive body, and dacite petrographically indistinguishable from the dacite forming Tumtum Mountain is also exposed in a gently sloping area at the north base of the mountain where it overlies glacial drift. The dacite exposed in this gently sloping area is a lava flow and not a debris flow or landslide material as shown by the accordant normal remnant magnetism of samples collected at nine places from the unit.

Lava forming Tumtum Mountain apparently rose to the surface along the northeasterly striking Chelatchie Fault. The Chelatchie Fault and a number of subparallel faults are postulated on the basis of mapped shear zones in the older Tertiary volcanics, and surface and subsurface topographic expressions of structure.

Tumtum Mountain is the youngest, western-most Quaternary volcano in the Cascades of Washington. Because lavas from Tumtum Mountain were erupted during the pre-Vashon interglacial interval, radiometric dating of Tumtum lavas might provide an absolute age for this interglacial interval.

Introduction

Tumtum Mountain is a symmetrical cone rising about 427 m (1400 ft) above the east end of Chelatchie Prairie, approximately 32 km (20 miles) southwest of Mt. St. Helens (Figure 1). During an investigation of the geology and groundwater resources of Clark County, Washington in the 1950's, Tumtum Mountain was described as a volcanic cone built on glacial deposits (Mundorff 1959, p. 43; 1964, p. 27). Both reports also stated that "A postulated fault trace along the southeastern margin of Chelatchie Prairie passes beneath Tumtum Mountain, and the volcanic material probably came up along the fault plane." The 1961 Washington State Geologic map (Huntting *et al.,* 1961) shows Tumtum Mountain as a Tertiary intrusive. In 1964, W. A. G. Bennett studied Tumtum Mountain as a potential source of feldspar (Bennett 1964). Bennett described Tumtum Mountain as a cone-shaped feature almost entirely covered by "talus consisting of fragments generally from a few inches to a foot or a few feet in diameter." According to Bennett (1964) the rock forming Tumtum Mountain is a very fine grained, light grey to greyish white, massive rock consisting predominantly of 0.1 to 0.2 mm andesine laths arranged in a trachytic texture, with rare 1 to 2 mm phenocrysts of hornblende and sparse dark grey inclusions up to 5 cm in diameter, in a zeolitized groundmass containing minute apatite needles and grains of an opaque mineral. In Bennett's study no determination as to the intrusive or extrusive nature of Tumtum Mountain was made.

Young felsic volcanic domes are common in the southern Cascades of Washington. Hopson's unpublished geologic map (1972) of Mt. St. Helens shows several dacitic domes which range in age from about 200 years B.P. to more than 35,000 years B.P. (Mullineaux and Crandell 1981). Hammond (1980) in his study of the southern Cascade Range of Washington describes several Quaternary-Tertiary felsic plug domes, flows and intrusions. The rock bodies include Goat Mountain, a dacite dome; Kalama dome; Mann Butte, a rhyolite dome; Gross Mountain, a dacite dome; and dacite and rhyolite domes of Simco Mountains (Hammond 1980). Field relationships, magnetic polarities, and radiometric dates (summarized by Hammond 1980) show that the age of these rock bodies ranges from more than 0.02 to 4.5 m.y. B.P.

During recent field studies of glaciation in the area Mundorff (1984) found additional evidence that Tumtum Mountain is an extrusive body which is younger than the pre-Fraser Amboy glacial drift. This report describes the

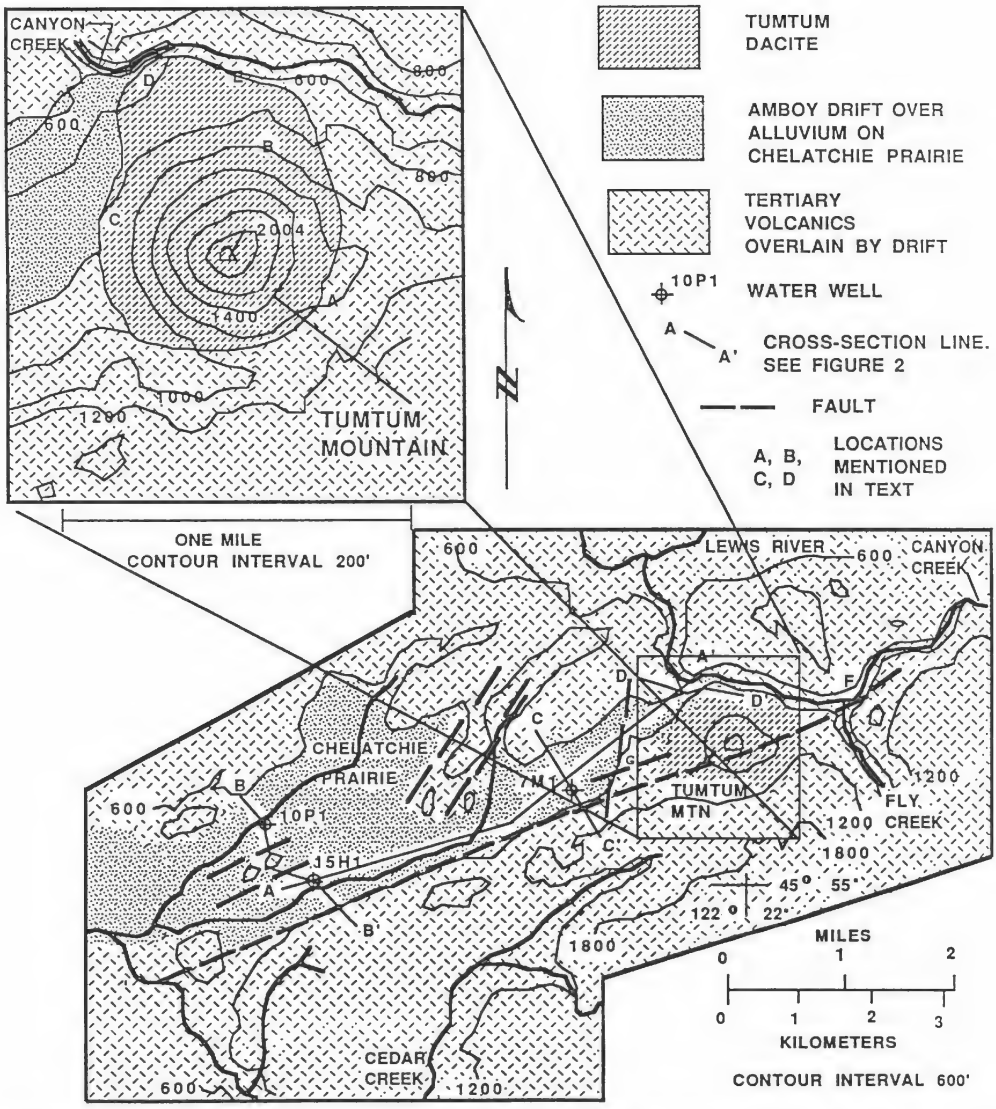

Figure 1. Geologic map of Tumtum Mountain and Chelatchie Prairie. Base map and topography are from the U.S.G.S. 15' Yacolt quadrangle.

geology of Tumtum Mountain in more detail, and presents convincing evidence that Tumtum Mountain and an adjacent triangular area at the north base of the mountain are a late Pleistocene extrusive body and lava flow.

Geology of the Surrounding Area

The rocks in the area surrounding Tumtum Mountain consist of intercalated lava flows, pyroclastics and sediments of late Eocene to Miocene age (Hammond 1980). Most of the rocks

in the immediate area consist of thick basalt flows. The flows are generally porphyritic and are greatly altered, and have developed a deep brown to reddish soil where erosion is absent. The rock in a quarry (location 1, Fig. 1) immediately adjacent to Tumtum Mountain, on a low ridge at the east side of the mountain, is a dark gray to bronze, porphyritic, greatly altered basalt. There is no evidence that any rock unit accumulated in the area between Miocene time and the late Pleistocene, thus an extremely long period of erosion and weathering intervened.

In the late Pleistocene, probably in early Wisconsin time, a large tongue of ice came down the Lewis River valley and spread widely across the lowlands and adjacent low hills and benches (Mundorff 1984). Amboy glacial drift deposited by this glacier forms a nearly continuous sheet over all rocks that were overridden by the ice. The ice reached an elevation of about 760 m (2500 ft) 13 km northeast of Tumtum Mountain and about 610 m (2000 ft) 5 km south of Tumtum. Projection of these and other points indicate that the top of the ice sheet probably was nearly 40 m higher than the present 611 m (2004 ft) elevation of the summit of Tumtum Mountain. If the mountain existed during Amboy time, the ice sheet would have eroded it, leaving glacial drift on its surface. Glacial drift deposited down slope would contain material plucked from Tumtum Mountain by Amboy ice. No glacial drift exists on Tumtum mountain, and the symmetrical shape of Tumtum indicates it was not eroded by glacial ice. No clasts of Tumtum origin have been identified in glacial drift down gradient from Tumtum Mountain.

The Rocks of Tumtum Mountain

Representative samples collected from outcrop and talus on Tumtum Mountain and from a gently sloping (about 3°) 0.12 km² triangular area at the north base of the mountain (see Figure 1) have a uniform lithology. Hand-specimens from Tumtum and the triangular area are massive and very fine grained. On a fresh surface the rock is light gray (N 7), and on a weathered surface the rock is grayish orange (10 YR 7/4). Megascopically the only visible constituents are sparse, scattered, black 1.5 mm amphibole needles, tiny plagioclase phenocrysts, and occasional dark xenoliths up to 3 to 4 cm in diameter (average size about 5 mm). Microscopically the rock consists predominantly (90 percent) of subhedral, zoned andesine laths with an average length of about 0.2 mm and an occasional andesine phenocryst up to 1.5 mm in length, all arrayed in a fluidal pattern. Resorbed amphibole phenocrysts up to 2 mm long are present in trace quantities. The interstices between the plagioclase laths are filled with a fine grained mineral with an index of refraction of about 1.49, and with low interference colors. As suggested by Bennett (1964) this intergranular mineral is probably a zeolite, perhaps chabazite or stilbite. Contained within the ground mass are abundant 0.05 mm apatite needles, and subhedral 0.02 mm grains of an opaque mineral. Although Bennett (1964) states quartz is a constituent of the rock, the authors identified no quartz in thin section.

A chemical analysis (W. H. Phillips, pers. comm. 1985) of a sample from Location 2 (Fig. 1) is given in Table 1. Normatively the rock is classified as a dacite according to the I.U.G.S. classification system (Streckeisen 1978).

TABLE 1. Chemical analysis and norm of Tumtum dacite. The analysis (supplied by W. H. Phillips 1985) was done by XRF by the Department of Geology, Washington State University for the Washington State Department of Natural Resources (D.N.R.), Division of Geology and Earth Resources of sample MK-TT-1. D.N.R. sample location: NE/4 S.8 (5N-4E), or Location B, Figure 1 in this paper. The analysis is normalized to 100% on a volatile-free basis, and Fe_2O_3/FeO is arbitrarily set at 0.87.

SiO_2	68.04	quartz	31.49
Al_2O_3	16.80	albite	27.48
TiO_2	0.52	anorthite	19.56
Fe_2O_3	1.94	orthoclase	9.13
FeO	2.22	diopside	0
MnO	0.10	hypersthene	5.17
CaO	3.94	magnetite	1.22
MgO	1.52	corundum	2.57
K_2O	1.54	ilmenite	0.90
Na_2O	3.25	apatite	0.30
P_2O_5	0.13		

The morphology of Tumtum Mountain, a symmetrical cone with concave slopes, and the gently sloping triangular area at the north base of the mountain, suggest a composite cone and flanking lava flow. However, the rocks which form Tumtum Mountain bear little resemblance to typical flows and pyroclastics which form composite cones. The rocks are more similar to those

which form volcanic domes and shallow intrusive bodies. The most significant fact with respect to the morphology of Tumtum Mountain is that the mountain is symmetrical, while other landforms in the area are asymmetrical because of glacial erosion.

The mountain is almost entirely mantled with talus consisting of angular, platy fragments of dacite in a sandy and silty matrix. This talus is well exposed in a quarry on the north flank of the mountain at an elevation of 275-305 m (900 to 1000 ft) (Location 2, Figure 1) where excavation has exposed 6 to 7 m of talus. The talus fragments are subangular with most fragments between 1 to 15 cm in diameter. Less than two percent of the material exposed on the mountain consists of blocks larger than 0.5 m in maximum dimension. The talus fragments are very platy; as an example, one slab of rock 2-3 cm thick and about 28 by 51 cm was split from a thick block with a geologic pick. No fragments of any rock type other than dacite were observed in the talus. No glacial erratics were observed on the surface of Tumtum Mountain.

At only two places on the mountain were outcrops observed: in a 10 by 25 m area at the summit, and along a logging road at the west base of the mountain (Location 3 on Fig. 1). Along the logging road Tumtum dacite crops out for a distance of nearly 40 m at an elevation of about 775 ft (236 m). The rock cannot be traced continuously as a single unit, but outcrops of 3 to 4 m interrupted by soil-covered areas and almost continuous bedrock forming the surface of the road suggest a continuous unit.

Dacite petrographically indistinguishable from the dacite exposed in outcrop and forming talus on Tumtum Mountain is well exposed in road cuts along the south rim of Canyon Creek valley (Locations 4 and 5, Fig. 1). At these locations 1 to 3 m angular blocks of massive dacite crop out in a 6 to 10 m thick zone which can be traced laterally for distances of 100 to 150 meters along the canyon rim. Because vegetation and soil cover bedrock between the exposed dacite blocks, direct field observation cannot determine if the 6 to 10 m thick layer formed as a landslide deposit of transported dacite blocks, or if the dacite blocks are in place as part of a lava flow.

Oriented samples of Tumtum dacite were collected at Locations 2, 4, and 5 (Fig. 1). The magnetic declination, inclination and polarity of samples collected from blocks formed in place should be uniform, and the magnetic vectors of samples of transported blocks should be randomly oriented. Magnetic declinations, inclinations, and polarities were estimated using a fluxgate magnetometer. With the probe of the magnetometer in place, oriented samples were rotated to the positions of maximum positive and negative deflection. Those positions were marked on the oriented samples, and compared to magnetic north and the horizon.

As a control seven oriented samples were collected from the quarry in talus on the north flank of Tumtum Mountain (Location 2). The individual samples were subangular blocks ranging from 15-20 cm in length and width and averaging about 10 cm in thickness. Of the seven talus blocks examined two had declinations and inclinations similar to the Earth's present field, and normal polarities. The other five samples had magnetic declinations and inclinations oriented 70° to 90° to the prevailing field.

Five oriented samples (equant blocks about 30 by 30 cm) were collected at intervals over about 45 m of outcrop along the road at location 4 (Fig. 1), and four oriented samples were collected from the outcrops at location 5 (Fig. 1). All nine of the oriented samples had normal polarities, with declinations and inclinations similar to the prevailing field. Because it is unlikely that dacite blocks in a debris flow or landslide would have uniform remnant magnetic polarities and orientations we conclude the dacite blocks are in place, and are from a 6 to 10 m thick lava flow which formed on the north flank of Tumtum Mountain.

The lava flow overlies Amboy Drift along the south rim of Canyon Creek valley. At Location 5 massive Tumtum dacite overlies a 40-50 cm layer consisting of fragments of Tumtum dacite in a matrix of fine sand and silt, which covers 9 to 10 m of boulder till (Amboy Drift) which, in turn, overlies Tertiary volcanic rock. At Location 4 soil slump and dense vegetation now obscures the relation of Tumtum dacite to underlying rock. However, field notes by Mundorff (8-31-55) stated that a new road cut at the south end of the bridge exposed massive Tumtum rocks overlying glacial drift at several places; and that at the southeast corner of the bridge, boulder till underlies Tumtum volcanics and

overlies dark gray to brown, moderately coarse, slightly amygduloidal volcanic rock.

The normal magnetic polarity of Tumtum dacite indicates a possible age of less than 700,000 years. Carbon 14 dating of wood fragments from the Amboy Drift indicates an age of more than 60,000 years (Mundorff, 1984). In the Canyon Creek area Amboy Drift is covered by the 35,000 to 40,000 years old (Mullineaux and Crandell 1981) St. Helens ash layer C (Mundorff 1984).

The time interval between Amboy glaciation and the eruption of Tumtum is indicated by weathering rind thickness measured on pebbles from Amboy Drift. At Location 5 pebbles from the upper 0.5 m of Amboy Drift, immediately below the 40-50 cm layer of fragmental Tumtum dacite, were collected for measurement of rind thickness. The range in thickness for the 20 stones examined was 0 to 0.4 mm, and the average rind thickness was 0.18 mm. This did not include three stones up to 5 by 10 cm that were completely decayed. The average rind thickness of these stones is less than that on stones found in 12,000 year old Vashon drift (Mundorff, 1984, p. 280). If it is assumed that all rind development on the stones found beneath Tumtum dacite occurred in the interval between deposition of the drift and extrusion of the dacite, then that interval could have been less than 12,000 years.

Chelatchie Prairie Faults

Chelatchie Prairie is an alluvial-filled, flat-bottomed basin up to 2.4 km wide. The prairie slopes from an elevation of about 180 m at its northeastern end where it is abruptly terminated by the deep gorge of Canyon Creek, to 122 m at Amboy, a distance of 8.5 km. Chelatchie Prairie apparently is a filled, down-faulted basin with a major fault zone along its southeastern margin (See Figure 1). A longitudinal profile and three cross sections based on well logs from the Chelatchie Basin are shown in Figure 2. The main fault zone extends northeastward beneath Tumtum Mountain and is well exposed 1.5 km northeast of Tumtum. The best exposure of the Chelatchie fault is in a 6 to 8 m road cut at Location 6 (Fig. 1). The fault zone is a vertical to near vertical 15 to 18 m wide zone of gouge and shattered rock.

A subsidiary fault can be seen in a quarry (Location 7) about 250 m west of the Chelatchie fault. This fault is best exposed at the south end of the pit where the width of the zone is 12 to 15 m. The apparent strike is about S 70°W and the dip is near-vertical, perhaps a few degrees to the northwest. The fault in this quarry is approximately parallel to the main Chelatchie fault.

The topography, the outcrops of the Tertiary volcanic rocks that protrude through the alluvial and glacial fill, and the logs of wells drilled on the prairie suggest a number of faults in addition to the main Chelatchie fault, as postulated in Figure 2. One of these is a cross fault 1 to 1-1/2 km west of the northeastern end of the basin. This fault is indicated by: A) older Tertiary volcanic rock exposed from the bottom of Canyon Creek to an elevation of 162 m where it is overlain by 15-20 m of Amboy Drift, and B) about 1 km to the southwest a low hill of Tertiary volcanics, rising to an elevation of 200-215 m, occupies the southeastern half of the basin. The Tertiary rock drops abruptly to the southwest where, in less than 1/2 km it is encountered in a well at an elevation of 95 m beneath 66 m of drift and alluvium. The postulated faults are shown in Figure 1.

Conclusions

Evidence that Tumtum Mountain is an extrusive volcanic feature of post-glacial age are summarized as follows:

1. The form of Tumtum Mountain, a symmetrical conical peak, indicates it was not eroded by glacial ice even though the loose talus at the surface of Tumtum would have been very susceptible to erosion.
2. No glacial deposits are found on the mountain although the pre-Fraser Amboy glacier would have overtopped the mountain had it existed during glaciation, and there are no Tumtum stones found in Amboy Drift down gradient.
3. The nature of the rock of Tumtum Mountain, a very fine grained, light buff to gray, platy dacite, is that of a volcanic rock.
4. Tumtum dacite overlies Amboy Drift in a gently sloping area of about 0.12 km^2 at the north base of the mountain. That this is a volcanic flow unit and not landslide debris

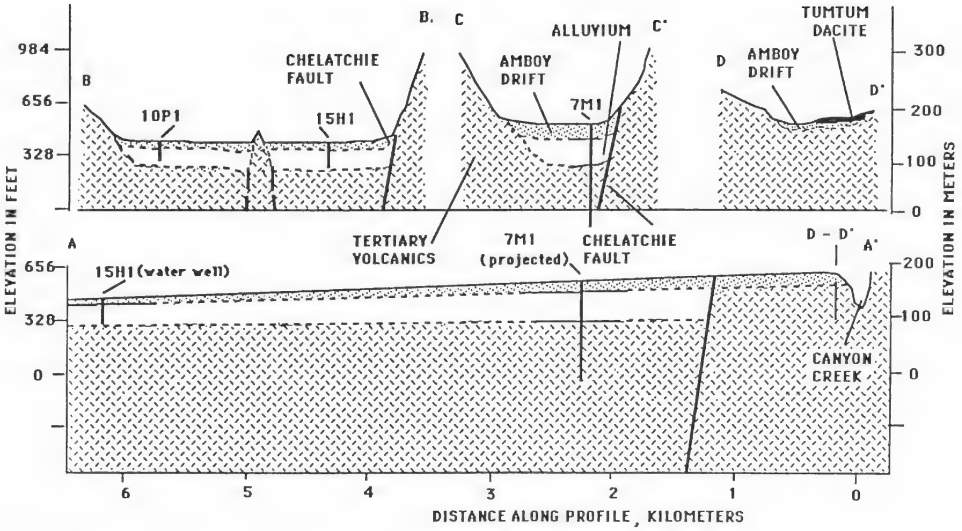

Figure 2. Longitudinal and transverse geological cross-sections of Chelatchie Prairie.

is indicated by uniformity of orientation of remnant magnetism throughout the unit.

Tumtum Mountain sits astride, and was probably erupted from, the northeasterly striking Chelatchie fault zone. The fault zone is indicated by prominent scarps, both in surface expression and in the subsurface as shown by well logs, and by wide shear zones which align with the scarps.

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Movement of Lauricidin in Douglas-fir Stumps Infested by *Phellinus weirii*

Abstract

Phellinus weirii (Murr.) Gilb., cause of laminated root rot, infects nearly all commercially important conifer species in the western United States and Canada. Infection in a young stand occurs when developing roots of young trees contact residual infested roots and stumps from a preceding stand. Although soil fumigants applied to infested stumps will reduce the amount of inoculum, the chemicals are highly toxic and require special handling. We are interested in developing stump treatments that are safe and environmentally acceptable. Because Lauricidin, a fungicide, has been demonstrated both to inhibit *P. weirii* and to be of low mammalian toxicity, it was tested as a candidate control agent. Two concentrations of Lauricidin in a carrier solution of dimethyl sulfoxide (DMSO) and ethylenediaminetetraacetic acid (EDTA), and the carrier solution alone, were applied to holes drilled in the tops of Douglas-fir (*Pseudotsuga menziesii*) stumps infested by *P. weirii.* Half of the stumps were evaluated after 4 months and the rest after 32 months. Lauricidin did not appear to move significantly in the stumps or roots. Any effect of the treatments on survival of *P. weirii* occurred near the treatment application holes and appeared to be caused by the carrier solution. We concluded that the formulation of Lauricidin tested in this study is relatively immobile in wood and for that reason a poor choice as a chemical for treating stumps to control *P. weirii.*

Introduction

Phellinus weirii (Murr.) Gilb. causes the most important root rot of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in the western United States and Canada. Infection in a young stand begins through contact between developing roots and residual infected stumps and roots from a preceding stand. Control of this disease has mainly focused on interrupting the disease cycle at the time of stand regeneration (Thies 1984). One experimental approach has been to chemically treat infested stumps at harvest to eliminate the fungus. Desirable chemical treatments would be those having antifungal properties with low toxicity to nontarget organisms, and ease of handling.

Lauricidin,[1] the trade name of monolaurin with more than 90-percent monoester attached to the first glycerol hydroxyl group, inhibits growth of *P. weirii, Fomes annosus* (Fr.) Karst. (Li and Kabara 1978), and other wood-decaying basidiomycetes (Li and Aho 1984) *in vitro.* Lauricidin, alone or in combination with ethylenediaminetetraacetic acid (EDTA), reduced colonization of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) stem sections from spores of *F. annosus* (Li and Kabara 1978). EDTA added to treatment solutions improved the ability of Lauricidin to inhibit *P. weirii* (Li and Kabara 1978) and other hymenomycetous fungi (Li and Aho 1984). These results led to a test that demonstrated the usefulness of Lauricidin as a stump surface protectant to reduce infection by *F. annosus* from spores (Nelson and Li 1980).

Lauricidin is nontoxic to humans, is approved by the U.S. Food and Drug Administration as a food emulsifier, and has been classified by that agency as Generally Regarded As Safe (GRAS; reg. No. 21 CFR GRAS 182.4505). Because Lauricidin has been demonstrated to both inhibit *P. weirii* and be of low mammalian toxicity, it was applied to *P. weirii*-infested stumps and its distribution within the roots estimated 4 and 32 months later. This paper reports the results of that field test.

Methods and Materials

Stumps

The study area was a 45-year-old Douglas-fir stand in the Oregon Coast Range near Apiary, Oregon (46°N. latitude, 121°W. longitude). Forty freshly cut Douglas-fir stumps, ranging from 26 to 67 cm in diameter and showing symptoms of *P. weirii* infection, were selected. A disk was cut

[1]This paper reports the results of research only. Mention of a pesticide does not constitute a recommendation for use by the U.S. Department of Agriculture, nor does it imply registration under The Federal Insecticide, Fungicide, and Rodenticide Act as amended. Also, mention of a commercial or proprietary product does not constitute recommendation or endorsement by the U.S. Department of Agriculture.

from the top of each stump, leaving the stump 30 cm high. Each disk was labeled and stored in a plastic bag. The pretreatment presence of *P. weirii* was later verified by culturing from stained or decayed areas of each disk and examining morphological features of resulting colonies (Nelson 1975). From our experience (Thies unpublished data), *P. weirii* is not present in wood that is not stained or decayed.

Stumps were stratified into five groups of eight stumps based on similarities in stump diameter and amount and stage of decay observed on the stump top. In a natural stand, considerable variation occurs among stumps with regard to size and shape. Additionally, among infected trees there is a continuum of stages of the disease from just infected to standing dead. Stumps were first stratified based on diameter of the stump top: small—less than 29 cm; medium—29 cm to 43 cm; and large—greater than 43 cm. The large stumps were further stratified into three groups based on the amount of stain or advanced decay observed on the stump top: 1. complete or nearly complete ring of stain at the sapwood-heartwood interface; 2. numerous spots or arcs of stain but not forming a contiguous ring; 3. few spots of stain. Stumps were selected so as to achieve five distinct groups and to minimize variability within each group. The eight treatments were assigned at random to the eight stumps in each group, thereby creating a randomized complete block experimental design.

Treatments

The eight treatments are combinations of four solutions with two intervals of exposure. Stump and root excavation and examination is necessarily destructive and hence the need to examine a different set of stumps for each interval of exposure. Lauricidin was dissolved in dimethyl sulfoxide (DMSO) to aid in distributing Lauricidin in the wood. Four treatment solutions were placed in stumps: 1. low—100 g Lauricidin, 1000 ml DMSO, 1.0 g EDTA; 2. high—700 g Lauricidin, 1000 ml DMSO, 1.0 g EDTA; 3. DMSO—1000 ml DMSO, 1.0 g EDTA; 4. check—nothing added. Check stumps were drilled and plugged but nothing was added to the stump.

Treatment holes, 2.5 cm in diameter, were drilled vertically into each stump top, including checks. Two holes extending into the root collar area but not through the bottom of the stump were drilled into each quadrant of the stump top. After treatment, each hole was plugged with a 2.5-cm-diameter by 5-cm-long hemlock dowel.

Data Collection

Stumps were treated in May 1981 and sampled in either September 1981 or February 1984. Of the 40 stumps initially included in this study, 3 did not yield *P. weirii* from the pretreatment sample and were not further evaluated. We conducted assays using *P. weirii* and *Streptococcus mutans* #6715 (Kabara *et al.* 1978) to determine how far biologically active concentrations of Lauricidin had migrated from the treatment holes into stump and root wood.

After each of the exposure intervals, samples were collected from appropriate stumps to determine the presence of viable *P. weirii* within the stump and roots. Stumps were bulldozed from the soil in a manner to retain intact as many major roots as possible, and the root surfaces were cleaned. After removing and discarding the top 5 cm of each stump, we cut an additional 10- to 15-cm disk and split it along radii between treatment holes into blocks. Blocks with stain or advanced decayed wood typical of *P. weirii* surrounding a treatment hole were labeled and stored in plastic bags. Blocks without stain were discarded.

Based on 1981 results, root systems were sampled less intensively in 1984 than in 1981. In 1981, 5-cm-thick disks were removed at 30-cm intervals along each root from the stump to a minimum root diameter of 5 cm. In 1984, a 5-cm-thick disk was removed from each of two infected roots 1 m from each stump. Disks with stain or advanced decay typical of *P. weirii* infection were labeled as to location, placed in plastic bags, and stored at 4°C.

Stump blocks and root disks from both treated and check stumps were sampled similarly. Each stump-sample block was split aseptically along three lines radiating from the hole towards the pith and 120° on either side (Nelson and Thies 1985). Wood chips were aseptically removed midway between the top and bottom of each split face starting 1 cm from the hole and at 1-cm increments across the face of the block in areas of typical stain or of advanced decay. Each root disk was split longitudinally through

stain or decay typical of *P. weirii.* Five chips were removed aseptically from the split face midway between the top and bottom of the disk in areas of typical stain or advanced decay. Each chip was placed on a tube slant of 1.5% malt agar with 1 ppm benomyl. Culture tubes were incubated for 14 days at room temperature. Presence of *P. weirii* was determined from morphological features of developing colonies (Nelson 1975). Tubes without colonies were incubated an additional 14 days and reexamined before discarding.

Samples from the 32-month collection were stored in plastic bags for 14 days at 4°C, and then for another 14 days at room temperature, before examination or isolation. When wood infested by *P. weirii* is stored in a closed plastic bag for 2 weeks at a moderate temperature (between 4°C and 20°C), the distinctive mycelium and setal hyphae of *P. weirii* will commonly grow onto the wood surface to form a thick brown felt on areas with typical stain or advanced decay (Thies and Nelson 1987). After storage, disks with the distinctive felt were recorded as positive for *P. weirii* without an attempt to culture the fungus. Disks lacking a felt or with a weak felt (scattered mycelium and few setal hyphae) were evaluated by culturing.

In addition to isolation of *P. weirii,* a modified bioassay using *Streptococcus mutans* #6715 (Kabara *et al.* 1978) was used to detect the presence of Lauricidin in stump samples collected in 1984. Each stump block was split radially through a treatment hole. Sample locations were marked on a split face 2 and 8 cm from the treatment hole on clear or stained wood but not on areas of advanced decayed wood. A wood sample was collected (Figure 1) by first drilling a 3-cm-diameter hole 0.5 cm deep at each sample point to remove potentially contaminated surface wood. Then, chips were collected from a 1.0-cm hole drilled 2.0 cm deep at the same point. The chips were ground to pass a 40-mesh screen, steam sterilized by autoclaving for 15 min, moistened with sterile distilled water, pressed into a disk 1.0 cm in diameter by 2 mm thick, and placed in the center of a trypticase-soy agar plate previously seeded with 10^8 cells of *S. mutans.* After incubation at 30°C for 24 to 48 hours, each plate was examined for zones of inhibition. As a standard for comparing inhibition zones, 12.7 mm paper disks were seeded with 25-, 50-, or 100-μg of Lauricidin in a water solution and then placed on plates and assayed in the same manner as the ground wood disks.

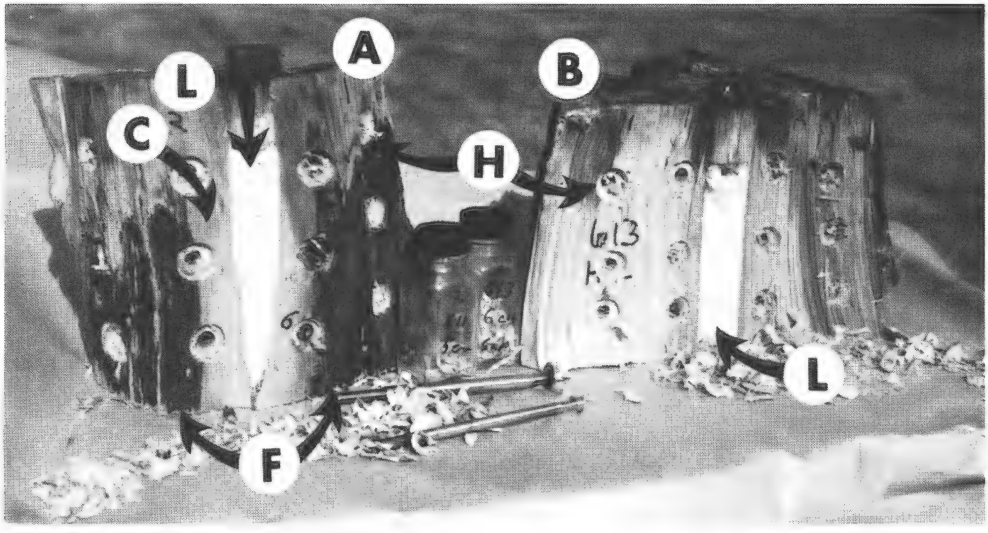

Figure 1. Stump top samples from stumps treated with Lauricidin and the carrier solution of DMSO and EDTA. A—Block infested by *Phellinus weirii.* B—Block not infested by *P. weirii.* H—Holes created while extracting wood samples. L—Lauricidin in treatment holes. F—Felt formed on infested wood by *P. weirii.* C—Zone of clear wood without a *P. weirii*-felt on the infested block.

Results

Lauricidin did not appear to move significantly in the stumps or roots. Stumps split open either 4 months or 32 months after treatment revealed Lauricidin in the treatment holes and active *P. weirii* in wood near these holes.

Lauricidin was found in treatment holes drilled in either sound or stained wood. The amount of Lauricidin that remained in the treatment holes was not measured; however, holes in both sound and stained wood were filled with Lauricidin, without noticeable voids (Figure 1). Treatment holes in advanced decayed wood contained little if any Lauricidin; however, advanced decayed wood less than 2 cm from the treatment holes appeared whitish and infiltrated by Lauricidin. Advanced decayed wood in stumps receiving either the check or DMSO treatment did not have whitish deposit. Advanced decayed wood probably offered little resistance to the flow of the treatment solutions, so that the Lauricidin was carried a short distance into spaces in the wood with the flow of the solution.

At the 4-month evaluation, *P. weirii* was recovered from all stump and root sample disks from both solution- and check-treated stumps. Proximity to the treatment hole did not influence recovery of *P. weirii.* The fungus was cultured from chips collected as close as 1 cm from treatment holes. These samples were not tested with the *S. mutans.*

At the 32-month sampling, a *P. weirii* felt was observed on blocks from 15 of the 17 stumps evaluated. Three stumps, one from each treatment group receiving a solution, were not evaluated; two were lost and one was eliminated because *P. weirii* was not recovered from the pretreatment sample. All five nontreated control stumps had a strong felt on both stump and root samples associated with the presence of stain or advanced decay typical of *P. weirii.* The felt covered only wood with *P. weirii* stain or advanced decay and formed a clear line of demarcation with areas of sound wood. Some areas of advanced decay did not appear to support the felt, and attempts to culture *P. weirii* from these areas were not successful. This finding is consistent with observations made in other studies (Thies and Nelson 1987). Of the 12 treated stumps, 2 were negative for *P. weirii* based on observations for felt or cultures from wood at the 32-month sampling; however, *P. weirii* was isolated from pretreatment samples from both stumps. These stumps were the two smallest (29 cm in diameter) evaluated at the 32-month sampling (mean diameter for stumps in the study was 43 cm) and were treated with solutions containing Lauricidin (one high, one low). Both were from a replicate containing stumps with significant amounts of advanced decay on the stump surface. Because of their size, these two stumps received the highest dosage of treatment solution per kilogram of stump and root biomass. Of the five stumps with a weak felt (suggesting some treatment effect), four were stumps from replicate blocks with significant advanced decay. Two of these five stumps were treated only with the carrier solution (DMSO and EDTA).

Felt developed around holes in untreated (check) stumps but not around holes that received a treatment solution. The distinct clear zones appeared on endgrain as well as split surfaces, and extended 2 to 4 cm from each hole (Figure 1). Attempts to isolate *P. weirii* from wood beneath clear zones were unsuccessful, although the fungus could be isolated from beneath adjacent felt-covered wood. The clear zones appeared the same whether or not Lauricidin was part of the treatment solution.

As we dissected the root systems, we could smell DMSO at many points, some as far as 2 m from the stump where the roots were as small as 5 cm in diameter. Many root samples that were returned to the lab had both the stain typical of *P. weirii* and the odor of DMSO. After incubation, stained sections often developed a heavy felt; however, root samples with advanced decay and the odor of DMSO usually developed little or no felt. Root samples, from untreated stumps, that had advanced decay usually developed a felt.

The bioassay for Lauricidin using *S. mutans* appeared to be very sensitive. Zones of inhibition extended a mean of 7 mm from paper disks with 25-μg samples and 26 mm from disks with 100-μg samples. We did not detect Lauricidin in prepared wood samples from any treated stumps. Failing to detect Lauricidin in the stump samples, we did not process root samples.

Discussion

The formulation of Lauricidin tested in this study is relatively immobile in wood and for that reason

appears a poor choice as a chemical for treating stumps to control *P. weirii.* Observed treatment effects on *P. weirii* seem to be due to the carrier solution, which eradicated the fungus only near the treatment holes, even where there was advanced decay. DMSO, however, appeared able to penetrate much of the root system of treated stumps.

Lauricidin has many desirable qualities that may yet allow it to be used in an effective control program. In view of the desirable and relatively safe nature of this compound, more research should be encouraged to develop and field-test formulations and application techniques that will result in better distribution of Lauricidin in stumps and root systems.

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Transferrin and Hemoglobin Polymorphism in Feral Horses (*Equus caballus*)

Abstract

The North American feral horse (*Equus caballus*) is quite abundant (45,000-50,000) yet little is known about their origins, the genetic composition of this population, or their relationships to domestic breeds. To study these relationships we examined protein variations in hemoglobin and the plasma enzyme transferrin among feral and domestic horses to assess their relationship to one another. Eighty-six feral horses from six genetically isolated herds represented (1) Pryor Mountain, MT, (2) Challis, ID, (3) Modoc, CA, (4) Powell Mt., NV, (5) Devil's Lake, CA, and Kiger Plateau, OR. Nine domestic horses described as Barbs, from Porterville, CA were also examined. Plasma transferrins were separated by polyacrylamide gel electrophoresis; whole blood was subjected to isoelectric focusing to identify hemoglobin polymorphisms. Four different transferrin variants were identified and the Pryor and Challis horses differed significantly ($P < 0.02$) from the entire population in transferrin frequencies. Interherd variation was less among the five far western herds than between themselves and the Pryor and Challis horses. Four hemoglobin alleles were identified, and only the Pryor horses failed to conform to Hardy-Weinberg equilibrium. The Porterville Barbs were indistinguishable from the feral horses on the basis of transferrin and hemoglobin polymorphism. It appears the Pryor horses, and to a lesser degree the Challis horses, have different transferrin and/or hemoglobin polymorphisms from the five other herds. In general, they show less diversity among these two parameters. The causes for this lack of diversity are not known but may be the result of a population bottleneck and genetic drift, or substantially different origins from the other herds.

Introduction

In spite of a relatively large population, relatively little is known about either the origin or biology of the North American feral horse (*Equus caballus*). These horses, estimated at 45,000 to 50,000 in number, represent a myriad of breeds and it has become increasingly apparent that feral horses are not a homogenous population. There appear to be significant differences between feral horses and their domestic counterparts, and between different herds of feral horses with respect to anatomy (Hall 1972), size (Hall 1972, Denhardt 1948), color patterns (Hall 1972, Feist 1971), behavior (Boyd 1979, Miller 1979, Nelson 1980, Klingel 1979), adrenal physiology (Kirkpatrick *et al.* 1977) and reproductive biology (Kirkpatrick and Turner 1986). However, the aforementioned differences between various populations of feral horses and between feral horses and domestic horses are the interpretations of endocrinologists, behaviorists, and reproductive physiologists. A shift to genetic studies is a logical next approach to learning more about the diversity of feral horses.

The examination of serum proteins has been used successfully to distinguish various breeds of domestic horses (Gahne 1966, Kaminski 1965, 1969, 1970, Helms and Allen 1971, Allen and Dalton 1975) as well as for various captive populations of Przewalskii's Horse (Podlizchouk and Kaminski 1971), mules, donkeys and zebras (Blake *et al.* 1981, Osterhoff 1966) and Icelandic ponies (Hesselhot 1966). Kaminski (1978) has shown differences in transferrin phenotypes which are striking and significant for different horse breeds and populations.

Kilmartin and Clegg (1967) and Clegg (1970) demonstrated four distinct heritable alpha-chain sequences. Isoelectric focusing techniques have been used by Ryder *et al.* (1979) to identify hemoglobin polymorphisms and their frequencies in *E. przewalskii.*

Since no previous studies of feral horse genetics have been reported, it was of interest to examine this aspect of their biology. Consequently, allelic variations and frequencies at the transferrin locus, and of hemoglobin were examined among six genetically isolated feral horse herds in the western United States and a herd of domestic horses described as Barbs.

Methods and Materials

Whole blood and plasma samples were collected from 86 feral horses from six different and reproductively isolated herds. The herds included Pryor Mountain, Montana (N = 8), Kiger Plateau, Oregon (N = 21), Challis, Idaho (N = 9), Modoc, CA (N = 23), Powell Mountain (Inyo National

Forest, Nevada) (N=8), and Devil's Lake, CA (N=17) (Figure 1). Whole blood and plasma were also collected from nine domestic horses belonging to the Wild Horse Research Farm in Porterville, CA. These latter horses were said to be Barbs, a breed originally indigenous to North Africa. Blood was collected by venipuncture from horses gathered by roundup, and stored frozen as plasma or whole blood. It was impossible to separate horses by harem band and herd location was the only characterization possible.

Figure 1. Geographic location of study herds.

Transferrins were separated from other blood proteins by vertical polyacrylamide slab-gel electrophoresis as described by Maizel (1971). Stacking and resolving gels were 2.5 percent and 7.5 percent polyacrylamide respectively. Samples were prepared for electrophoresis by placing 3 microliter plasma aliquots in 3 microliters of Tris-chloride buffer/glycerol, pH 6.7, and one microliter of 0.25 percent bromphenol blue. Five microliter samples of this mixture were subjected to electrophoresis.

Electrophoresis was carried out on an LKB Multiphor 2117 electrophoresis unit. The buffer system was Tris-glycine, pH 8.3, as described by Davis (1964). Pre-electrophoresis, a condition necessary for concentrating the protein sample, was carried out for ten minutes at 50mA and 250 V. The remainder of the run was carried out at 200 V and 10°C for four hours. Proteins were stained with 0.025 percent Coomasie Blue R-250 and 5 percent acetic acid. Gels were stored in 3.5 percent acetic acid and photographed against a light table.

Hemoglobin polymorphism was examined by isoelectric focusing as described by Ryder (1979). The isoelectric focusing was carried out in 1.5 mm, 5.8 percent polyacrylamide horizontal slab-gels on an LKB Multiphor unit. Three ml of pH 6-8 ampholine (LKB) was incorporated in each gel. Blood samples were prepared by placing 20 microliters of red cell hemolysate in 50 microliters of 0.1 percent KCN. The hemolysate-KCN mixture was absorbed in 5 x 8 mm Whatman No. 3 filter paper and placed directly on the gel on the cathode side. The anode buffer was 1 m H_3PO_4 and the cathode buffer was 1 m NaOH. Isoelectric focusing was carried out at 25 mA and 400 V, at 10°C, for 30 minutes, after which the filter paper was removed. The focusing was continued at 900 V for three hours. Gels were fixed in 12.5 percent trichloroacetic acid.

Data were treated statistically by chi-square analysis. Differences were considered significant at the $P < 0.05$ level of confidence.

Results

Gel electrophoresis yielded four transferrin phenotypes among the 86 feral and nine domestic horses. These four alleles, depicted in Figure 2, were identified as Jf1, Ms1, Lj1, and La1 according to the classification scheme of Kaminski (1978). Table 1 gives the frequencies for each allele.

Chi-square analysis of observed allele frequencies did not, for the most part, violate those expected in a Hardy-Weinberg distribution. Allele frequencies for both the Pryor Mountain horses and the Challis horses differed significantly ($P < 0.02$) from the expected allele frequencies for the entire population examined. Chi-square analysis of allele frequencies between individual herds revealed significant differences in 14 of 21 comparisons (Table 2). Nine of those significant differences (or 64% of the total significant differences) were found between the Pryor Mountain horses (5) and other herds and the Challis horses (4) and other herds.

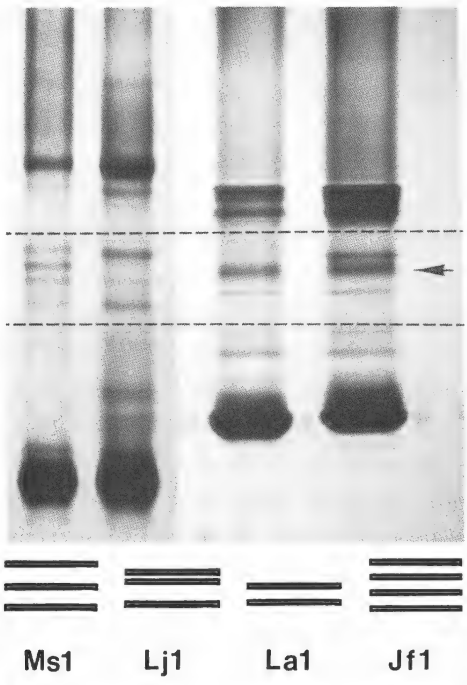

Figure 2. Banding patterns for the four transferrin polymorphisms. The four different forms of the enzyme transferrin are indicated by the protein bands between the dashed lines.

Particular alleles were also examined for uniqueness to populations. The Lj1 allele was found in only two populations, the Pryor Mountain and Powell Mountain herds. In the Pryor Mountain herd it represented three of the eight horses examined (37.5%), whereas in the Powell Mountain herd it was found in only one of the eight horses. The Ms1 allele was most common, being displayed in all herds except the Challis group. In the other six herds this allele presented at a higher frequency than any other. In the Challis herd only the Jf1 allele was evident; this herd was the only one to demonstrate a single allele type. Several herds (Kiger, Modoc, Powell Mountain and Devil's Lake) contained horses possessing allele types unique to them within each population.

Isoelectric focusing of hemoglobin resulted in either two or four bands. The band or bands at the pH 8 side of the gel represent "slow" alpha hemoglobin, with $_{60}$lysine, while the band or bands at the pH 6 side represent "fast" alpha-hemoglobin, with $_{60}$glutamine. In turn, both the fast and slow hemoglobin variants have either $_{24}$tyr or $_{24}$phe, both of which have different isoelectric points. The genes controlling the hemoglobin variants are labeled BI ($a_f^{24\ tyr}$———$a_s^{24\ tyr}$) and BII ($a_f^{24\ phe}$———$a_s^{24\ phe}$). The hemoglobin genotypes for the 95 horses in this study are shown in Table 3. The BI and BII forms appear in approximately equal numbers and the frequencies for these genes for all herds, collectively, do not differ significantly ($P > 0.05$) from those expected in a Hardy-Weinberg distribution. Among individual herds, only the Pryor Mountain horses differed significantly ($P < 0.02$) from a Hardy-Weinberg distribution.

TABLE 1. Transferrin phenotype frequencies among one domestic and six feral populations of horses

Herd Location	N	Phenotype Jf1	Ms1	Lj1	La1	X^2	P
Pryor Mountain, MT	8	0	5	3	0	23.82	<0.02
Kiger Plateau, OR	21	8	12	0	1	2.60	>0.30
Challis, ID	9	9	0	0	0	24.71	<0.02
Modoc, CA	23	1	18	0	4	7.51	>0.05
Powell Mt., NV	8	0	7	0	1	3.35	>0.30
Devil's Lake, CA	17	7	9	1	0	3.35	>0.30
Porterville, CA	9	0	5	0	4	3.74	>0.30

TABLE 2. Comparison of observed transferrin allele frequencies between herds

Herd Location	N	Compared To	X^2	P
Pryor Mountain	8	—	—	—
	21	Kiger Plateau	11.30	<0.02
	9	Challis	19.64	<0.01
	23	Modoc	21.20	<0.01
	8	Powell Mt.	4.33	>0.10
	17	Devil's Lake	6.18	<0.05
	9	Porterville	7.00	<0.05
Kiger Plateau	21	—	—	—
	9	Challis	9.53	<0.01
	23	Modoc	7.75	<0.05
	8	Powell Mt.	4.34	>0.10
	17	Devil's Lake	1.81	>0.50
	9	Porterville	9.36	<0.01
Challis	9	—	—	—
	23	Modoc	28.07	<0.01
	8	Powell Mt.	16.99	<0.01
	17	Devil's Lake	8.59	<0.02
	9	Porterville	19.06	<0.01
Modoc	23	—	—	—
	8	Powell Mt.	0.62	>0.70
	17	Devil's Lake	11.82	<0.01
	9	Porterville	2.73	>0.20
Powell Mt.	8	—	—	—
	17	Devil's Lake	6.89	>0.05
	9	Porterville	2.28	>0.10
Devil's Lake	17	—	—	—
	9	Porterville	11.90	<0.01

TABLE 3. Hemoglobin Genotypes by Herd

		Genotype			
Herd Location	N	BI/BI	BI/BII	BII/BII	P
Pryor Mountain	8	5	2	1	<0.02
Kiger Plateau	21	3	9	9	>0.10
Challis	9	2	5	2	>0.95
Modoc	23	8	10	5	>0.50
Powell Mountain	8	1	5	2	>0.50
Devil's Lake	17	3	8	6	>0.50
Porterville	9	1	6	2	>0.50
Total	95	23	45	27	>0.70

(P = probability that genotype frequency differs from a normal Mendelian distribution by chance alone)

Discussion

There are four major points of interest which emerge from this study of feral horse genetics. First, of ten known transferrin variants in equids (Chung and McKenzie 1985) only four were identified among the 95 horses examined in this study. In a simlar study of 162 feral donkeys Blake *et al.* (1981) found all ten variants present. The ten variants are controlled by codominant autosomal alleles (Gahne 1966) and impart no known selective advantages. Considering the probable diverse origins of the present day feral horse herds, it might be expected that a larger number of variants would exist.

A second significant feature of this study is the possibility that one or more of the feral horse herds investigated possesses significant genetic differences from the others. The hypothesis tested was that the transferrin loci in all six feral herds and the domestic herd were in equilibrium. This hypothesis was rejected for both the Pryor herd ($X^2 = 23.82$, $P < 0.02$) and the Challis herd ($X^2 = 24.71$, $P < 0.02$). Additionally, the hypothesis that hemoglobin polymorphism conformed to a Hardy-Weinberg distribution among the 95 horses collectively and among each herd was tested. The hypothesis that the hemoglobin polymorphisms conformed to Hardy-Weinberg equilibrium among the entire 95 horses was not rejected ($X^2 = 0.59$, $P > 0.70$) but equilibrium among the Pryor horses was rejected ($X^2 = 6.0$, $P < 0.02$). This suggests that these two herds, the Pryor and Challis populations (1) have experienced a great deal of inbreeding over the years, (2) have different origins, or (3) have passed through significant genetic bottlenecks sometime in the past. The Pryor Mountain herd is well isolated by the Bighorn Basin of Wyoming and the Pryor Mountains of eastern Montana. Similarly, the Challis horses are separated from other herds by the Salmon River to the north, and mountains to the east, south and west. The remaining four feral herds, however, extend across a region—western Nevada north across northern California and into central Oregon—in which migration could easily have occurred. There are no formidable barriers across their collective ranges (Figure 1). Consequently, these data suggest a mixing of genes among the four westernmost herds and a genetic isolation among the Pryor and Challis herds, which is then reflected in differences in transferrin and hemoglobin polymorphisms. It has been presumed that the largest single source of feral horses was the stock turned loose during the Great Depression. During the almost 60 years since that time, or 10 to 12 generations of horses, it is purely speculative whether sufficient migration could have occurred to account for the homogeneity of the four western herds.

A second interpretation of the differences in polymorphism is that the eastern, and particularly the Montana horses had a very different origin than that of the western herds. Early journals document the existence of the Pryor horses as early as 1810. Little is known about the breedtype from which the present feral horse herds originated, but this must be considered as a possibility for genetic differences, or a lack thereof, among different populations. A third possibility is that of inbreeding. At the time of this study the Pryor herd had approximately 125 animals; Challis, 110; Kiger, 251; Modoc, 491; Powell Mountain, 240, and Devil's Lake, 136. The four western herds have historically been considerably larger than the Pryor or Challis herds. Anecdotal evidence indicates that the Pryor population may have been as low as 10-15 animals by about 1900; after two hard winters in 1977-78 and 1978-79, the Pryor herd was reduced to about 80 horses and less than 20 breeding stallions. Thus, the differences demonstrated by this study may merely reflect genetic drift, caused by a historical "bottleneck" and a degree of inbreeding in the small Pryor and Challis populations and a good mixing of genes in the other four. If inbreeding is suggested, it is noteworthy that neither the Pryor nor the Challis herds suffer from a decline in foaling rates, which are greater than 40 percent and consistent with most other western herds (Kirkpatrick and Turner 1986).

It is important to exercise some caution in interpreting these results, since only a small percentage of total herd populations were sampled. Of the 125 Pryor horses, only 8, or 6.4 percent, were sampled. Similar percentages of horses from other ranges were sampled, with the largest group (Modoc) still representing only 4.6 percent of the total population on that range. While statistical differences are evident, care must be taken in attributing these differences to entire populations.

Finally, the examination of transferrin and hemoglobin polymorphisms among the domestic Porterville Barbs failed to provide a unique genetic marker with which to distinguish these horses. In fact, the similarity of the transferrin polymorphisms between the Porterville horses and those of the four western herds, and particularly those of the Modoc range ($X^2 = 2.73$, $P > 0.20$) suggests a common origin; only five of the 14 significant differences among the 21 inter-herd comparisons were found among the four western feral herds and the Porterville herd. Also, with the exception of the Pryor Mountain herd, the hemoglobin polymorphisms for the other six herds were indistinguishable in form and frequency from those found in domestic breeds (Kilmartin and Clegg 1967) and *Equus przewalskii* (Ryder *et al.* 1979). The possibility that other genetic markers exist which might distinguish the Barbs of Porterville cannot be ruled out by this limited study.

The determination of effective population sizes in feral horse herds would be desirable (Berg 1986). Currently there are no data available inferring genetically effective population sizes in the particular herds studied, or for that matter in other North American feral horse herds. Availability of appropriate estimates, derived from a larger view of enzyme polymorphisms, could permit a modeling approach with which to examine the potential for genetic divergence in feral horse herds.

This pilot study has demonstrated significant differences in transferrin and hemoglobin polymorphisms between certain feral horse herds, and a similarity of those same parameters between a domestic herd of Barb horses and feral horses of Nevada, California, and Oregon. The recent work of George and Ryder (1986) which examined restriction endonuclease maps of mitochondrial DNA among domestic and exotic equids provides a much more powerful tool for examining the genetics of feral equids and directs the next logical step in this study.

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Short-term Vegetation Change After Dyke Breaching at the Kokish Marsh, Northeastern Vancouver Island

Abstract

Total or partial removal of dykes (termed breaching) to allow re-entry of tidal water is being used in some areas along the British Columbia coast to enhance previously dyked marshland for fish and waterfowl. To assess the extent of habitat change following dyke breaching at the Kokish River tidal marsh on northeastern Vancouver Island, we examined vegetation and soil conditions before and fifteen months after the dyke was breached. A low salinity undyked area of the Kokish marsh was used as a "control" to assess the impact of the breaching on the more saline dyked area's vegetation and soils. Little breaching related change was observed in the cover and frequency of most plant species, and in the soil salinity and organic content which remained high in the dyked area. Small changes in the main plant communities were detected by multivariate analysis, the largest change occurring in a dyked area plant community where *Carex lyngbyei*, a desired fish habitat species, increased noticeably following the breaching. The breach allows low salinity river water (ca. 2 ppt) to enter the dyked area, but not until a considerable amount of seawater (ca. 22 ppt) has already entered through an existing opening in the seaward section of the dyke. These results suggest that some coastal marsh plants (e.g. *Carex lyngbyei*) are sensitive to small changes in habitat conditions following dyke breaching. Greater changes in plant communities would require more substantial habitat change than was observed at the Kokish.

Introduction

In the early days of British Columbia's coastal settlement, dyke building was a major activity. Dykes were built to exclude sea water from pastures and cultivated fields, for causeways to permit transportation over waterlogged lands, and to prevent flooding in areas used for the storage and handling of logs (R.A. Hunter and L. E. Jones pers. comm.). Recently, with increased awareness of the need for suitable fish and waterfowl habitat, some dykes are being considered for total or partial removal (termed breaching). The aim of such an undertaking would be to restore previously dyked marshland to intertidal habitat thus increasing the area available to juvenile anadromids en route to the sea and augmenting natural food sources for waterfowl.

Little published information exists on the effects of dyking and dyke breaching in marshlands along the northern Pacific coast of North America. Taylor (1983) concluded that dyking led to vegetation change and land subsidence at a coastal site in Oregon. Bradfield and Campbell (1986) described different plant communities in adjacent dyked and undyked portions of two northern Vancouver Island marshes. Mitchell (1982) and Dawe and McIntosh (1987) noted vegetation changes within one year following sea-dyke breaching, including mortality of salt intolerant upland species, and the appearance of newly colonizing halophytes. A pre-restoration study of a dyked area which will be converted to estuarine intertidal habitat has been reported by Dawe and Jones (1986).

Previous studies at the Kokish marsh on northeastern Vancouver Island have proposed vegetation classifications for habitat inventory (Jones 1982, Kennedy 1982, Campbell 1986). The classifications are all similar, stressing different levels of detail in the marsh vegetation. The classification established by Campbell (1986) is used in this paper. Wayne (pers. comm.) discussed various rehabilitation options for the Kokish estuary in connection with salmon enhancement. Bradfield and Campbell (1986) reported stronger correlations between vegetation patterns and elevation gradients in the undyked than in the dyked portion of the Kokish marsh.

This paper describes the vegetation changes occurring by the second growing season following dyke breaching at the Kokish marsh. The objective of the dyke breaching was to allow river water to re-enter a dyked, saline area, thereby lowering salinity levels and expanding the habitat available for juvenile salmon. Our role in the restoration project was purely observational; the planning and implementation of the dyke breaching were part of a co-operative agreement between Fisheries and Oceans Canada and Canadian Forest Products Ltd. We used a multivariate

analytical approach to determine the extent of vegetation change: comparison of the main plant communities using data from pre- and post-breaching surveys in adjacent dyked and undyked portions of the Kokish marsh permitted the assessment of vegetation change due to dyke breaching.

Study Area

The Kokish River estuary is located in Beaver Cove, ca. 15 km south of Port McNeill on the northeastern coast of Vancouver Island (Figure 1). The Kokish estuary has developed on fluvial-fluvioglacial sediments and volcanically derived bedrock (Howes 1981). The climate is mild, with an average yearly air temperature of 8.5°C (average maximum temperature of 11.6°C; average minimum temperature of 5.4°C). The average annual precipitation is 1555 mm, 95 percent of which falls as rain (Anonymous 1981a). Monthly climate data during the study period 1984-1986 are given in Table 1.

TABLE 1. Meteorological data for the Kokish marsh during the period of study.

	Total Precipitation (mm)			Mean Temperature (°C)		
Month	1984	1985	1986	1984	1985	1986
January	247.4	95.0	369.0	4.8	4.7	5.4
February	160.0	158.7	85.5	5.8	3.6	3.3
March	81.0	92.6	168.4	7.6	5.0	7.2
April	117.0	125.3	114.9	7.4	6.5	6.9
May	120.4	45.5	142.8	9.0	10.0	9.9
June	52.3	56.1	92.4	11.6	11.9	12.0
July	59.5	7.1	41.8	13.9	14.8	14.0
August	113.7	20.6	1.2	14.1	13.7	14.7
September	118.9	46.0	103.8	11.7	11.3	12.1
October	262.1	235.5	198.8	7.9	7.9	11.4
November	201.5	76.4	375.3	4.5	0.3	5.9
December	185.4	92.0	213.4	1.7	3.4	5.0

Source of data:
Anonymous, 1984-1986.

A dyke bisecting the Kokish marsh was constructed during the early 1900's to facilitate log handling in the area. In the early 1940's, Canadian Forest Products Ltd. (Canfor) acquired lease to the site, and in 1954 a rail line was installed along the dyke with a trestle bridge spanning a narrow channel in the seaward section of the dyke which has permitted regular flooding of the dyked area by seawater (Figure 1). The rail line has since been removed, and part of the dyke is now used for burning wood debris. The only freshwater input into the dyked area before 1985 was from precipitation and a few small creeks.

Prior to the dyke breaching, the plant communities in the dyked and undyked areas were very different (Bradfield and Campbell 1986). In addition, the biomass of the dyked area was clearly lower than that of the undyked area. The dyke was breached 19 April 1985, allowing river water to enter the dyked area on a rising tide. The original seaward channel was left open, however, to allow tidal water to flow through both openings. It was predicted that the soil salinity of the dyked area would eventually decline, thus leading to greater productivity and a change in the vegetation from species such as *Salicornia virginica*[1] and *Triglochin maritimum,* to more desirable species from a fisheries perspective such as *Carex lyngbyei.*

Methods

Field work

The Kokish marsh vegetation was surveyed in July 1984 (nine months before the dyke was breached), and again in July 1986 (fifteen months after the dyke was breached). In July 1984, 214 0.25 m^2 quadrats were surveyed along 18 transects: 10 transects (126 quadrats) in the dyked area and 8 transects (88 quadrats) in the undyked area. Transect length ranged from 10 m to 145 m. The transects were subjectively placed in order to sample the entire elevation range and vegetation diversity (Figure 1). Quadrats were placed every 5 m along the transects, and, within each quadrat, the cover of each vascular plant species was subjectively estimated using a modified Braun-Blanquet cover/abundance scale (1 = <5%; 2 = 5-25%; 3 = 26-50%; 4 = 51-75%; 5 = 76-100%). This method of coverage estimation is not suitable for detailed studies on separate species, but is appropriate in vegetation surveys of large areas, such as ours, where constraints imposed by time and using different observers to record the data must be taken into account. The elevations of all quadrats above chart datum also were determined for the

[1]Nomenclature follows Hitchcock and Cronquist (1973).

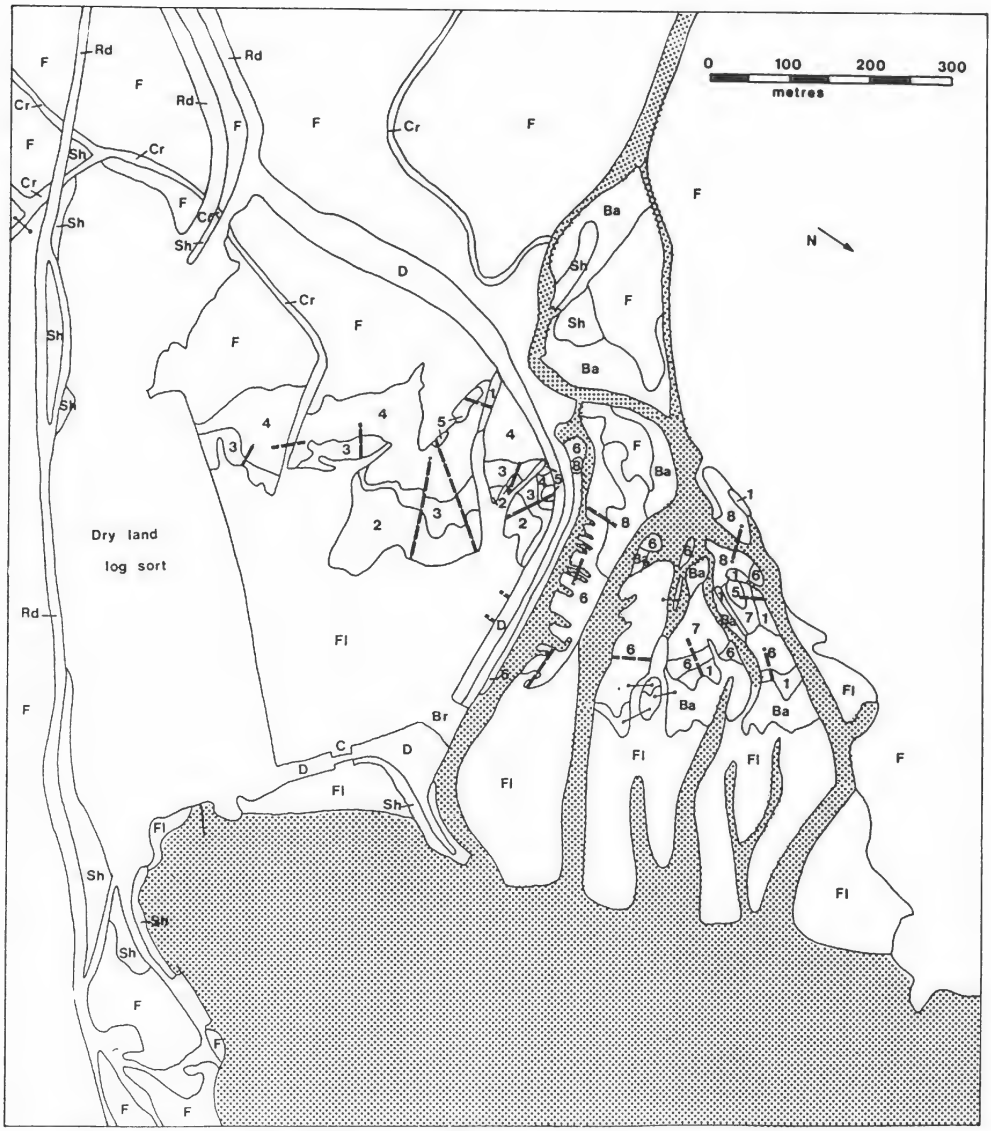

Figure 1. Map of the Kokish marsh showing the major plant communities and locations of transects used in the vegetation surveys. The undyked area lies to the north of the dyke; the dyked area lies to the south. Numbers denote plant communities described in Table 2. Other map symbols: Ba (bar), Cr (creek), D (dyke), F (forest), Fl (mudflat), Rd (road), Sh (shrub), C (original channel through seaward section of dyke), Br (breach opening created 19 April 1985).

purpose of relating vegetation pattern to tidal gradients. Additionally, 24 soil samples were randomly collected in the main plant communities recognized in the field (16 samples in the dyked area and 8 samples in the undyked area). A further 28 soil samples (10 dyked, 18 undyked) were collected during a brief visit to the Kokish marsh in July 1985.

In July 1986, exactly two years after the initial survey, the vegetation of the Kokish marsh was resampled. The original transects were relocated using air photos, 35 mm slides, and marker stakes remaining from the 1984 survey. Quadrats were placed along the transects as close as possible to their original locations. As in 1984, species cover was estimated using a 5-class coverage scale; however, the estimates were made by a different observer in 1986.

Water salinity measurements were periodically taken using an American Optical refractometer during a rising tide on 22 July 1986, to assess the salinity of the water entering the dyked area.

Thirty-two soil samples were collected in 1986: 14 in the dyked area and 18 in the undyked area. The 84 soil samples from 1984, 1985, and 1986 were analysed for percent organic matter by the loss on ignition method (Hesse 1971), and for electrical conductivity using the method described in the University of British Columbia Pedology Laboratory manual (Anonymous 1981b).

Data analysis

The plant community classification for the Kokish marsh described by Campbell (1986) was used in the assessment of vegetation change. Communities were originally defined subjectively by aerial photograph interpretation immediately following transect sampling in the field. Subsequent investigation with multivariate analysis of variance demonstrated that the communities explained high proportions of variance in the field data, and thus could be used as valid units for further study (Bradfield and Campbell 1986). Plant community changes were examined directly by comparing species cover and frequency data from the 1984 and 1986 transect surveys, and indirectly by using principal components analysis (PCA) to display changes in the multivariate pattern of the vegetation over the two year period. PCA is an appropriate technique for our purpose (i.e. to describe changes in groups); we did not attempt an environmental interpretation of the PCA axes. In the PCA's the species cover class data were treated as being continuous, quantitative variables. The results are similar to those from PCA of $\log_{10}$ transformed percent coverage data. Two separate PCA's were performed for the dyked and undyked areas using both the 1984 and 1986 coverage class data to assess within-area changes. PCA's were run using both presence-absence and quantitative (cover class) data but community changes were detected only using the cover class data. Ninety-five percent confidence ellipses for communities, calculated by the method of Owen and Chmielewski (1985), assisted in the visual assessment of the degree of change in communities that had occurred. To further examine the extent of overall change in the vegetation, irrespective of communities, four additional PCA's were performed, one for each combination of area (dyked or undyked), and year (1984 or 1986). Pearson correlation coefficients calculated between the 1984 and 1986 PCA axis scores for the separate areas were then examined based on the rationale that the area showing the greatest vegetation change would have lower correlations between PCA axes.

Results and Discussion

Community Change

Data permitting a detailed comparison of the major plant communities in 1984 and 1986 are given in Table 2. Most species increased in both frequency and cover over the two year period. These changes occurred in both the undyked and dyked areas and therefore reflect general expansion of populations within the marsh unrelated to dyke breaching. Nevertheless, a substantial increase in *Carex lyngbyei,* an important species from a fisheries perspective, occurred following breaching in dyked community 4 (Table 2b), with no corresponding increase in the undyked community, suggesting that this species was favoured by the dyke breaching.

The PCA ordinations illustrating the degree of change in communities are shown in Figure 2. Based on a visual assessment of these graphs, the extent of change in the undyked area communities (Figure 2 a & b) appears no less than that in the dyked area communities (Figure 2 c & d); thus, the dyke breaching *per se* appears to have had minimal short-term impact on the vegetation.

TABLE 2: Percent frequency (F) and mean coverage classes (C) of prominent[1] species in the main plant communities recognized at the Kokish marsh before (1984) and after (1986) dyke breaching occurred. Range of cover classes shown in parenthesis. Numbers on the left refer to plant communities shown in Figures 1 and 2.

a) Undyked area communities	1984		1986	
	F	C	F	C
1. *Carex lyngbyei*	100	2.7 (1-4)	100	2.7 (1-5)
5. *Elymus mollis*	100	5.0 (5-5)	100	5.0 (5-5)
Potentilla pacifica	100	3.0 (3-3)	100	3.7 (3-5)
Trifolium wormskjoldii	75	3.0 (3-3)	100	2.7 (2-3)
Hordeum brachyantherum	25	0.7 (0-1)	25	2.0 (0-3)
Deschampsia cespitosa	—	—	25	2.3 (0-5)
Agrostis alba	—	—	25	0.7 (0-2)
6. *Carex lyngbyei*	91	2.4 (0-4)	96	3.3 (0-5)
Deschampsia cespitosa	88	2.2 (0-4)	96	3.2 (0-5)
Potentilla pacifica	61	1.6 (0-4)	77	2.1 (0-5)
7. *Deschampsia cespitosa*	100	3.8 (3-5)	100	5.0 (5-5)
Potentilla pacifica	100	3.3 (2-4)	100	3.5 (1-5)
Hordeum brachyantherum	75	1.3 (0-3)	100	2.3 (2-3)
Carex lyngbyei	25	0.3 (0-1)	25	0.5 (0-2)
Trifolium wormskjoldii	—	—	25	0.5 (0-2)
Agrostis alba	—	—	25	0.3 (0-1)
8. *Deschampsia cespitosa*	100	3.2 (1-5)	100	4.6 (2-5)
Agrostis alba	95	1.5 (0-3)	100	4.0 (2-5)
Achillea millefolium	89	2.6 (0-4)	77	3.3 (0-5)
Potentilla pacifica	89	2.4 (0-4)	100	3.4 (1-5)
Festuca rubra	84	0.9 (0-2)	86	1.7 (0-4)
Trifolium wormskjoldii	79	1.6 (0-3)	73	1.8 (0-4)
Plantago macrocarpa	53	1.5 (0-5)	23	0.9 (0-5)
Hordeum brachyantherum	32	0.4 (0-2)	27	0.6 (0-3)
Stellaria humifusa	32	0.4 (0-3)	14	0.3 (0-2)
Maianthemum dilatatum	21	0.4 (0-3)	14	0.3 (0-2)
Conioselinum pacificum	16	0.2 (0-1)	23	0.3 (0-2)
Aster subspicatus	16	0.2 (0-2)	14	0.4 (0-3)
Juncus balticus	16	0.2 (0-2)	23	0.9 (0-5)
Heracleum lanatum	11	0.2 (0-2)	—	—
Sisyrinchium angustifolium	11	0.1 (0-1)	5	0.1 (0-1)
Elymus hirsutus	11	0.1 (0-1)	5	0.1 (0-2)
Carex lyngbyei	5	0.1 (0-1)	18	0.2 (0-2)

b) Dyked area communities	1984		1986	
	F	C	F	C
1. *Carex lyngbyei*	100	4.3 (2-5)	100	5.0 (5-5)
2. *Salicornia virginica*	78	2.2 (0-5)	71	2.3 (0-5)
Triglochin maritimum	64	1.4 (0-4)	69	1.8 (0-5)
Glaux maritima	31	0.4 (0-2)	51	1.3 (0-5)
Plantago maritima	22	0.4 (0-3)	9	0.2 (0-3)
Puccinellia pumila	22	0.4 (0-4)	46	1.5 (0-5)
Spergularia canadensis	22	0.2 (0-1)	57	1.1 (0-3)
3. *Triglochin maritimum*	97	2.2 (0-4)	100	2.6 (1-5)
Carex lyngbyei	94	3.2 (0-5)	96	3.5 (0-5)
Glaux maritima	53	0.6 (0-2)	54	1.1 (0-3)
Salicornia virginica	44	0.8 (0-4)	50	1.0 (0-5)
Puccinellia pumila	31	0.3 (0-2)	50	1.5 (0-5)
Stellaria humifusa	39	0.6 (0-3)	46	1.1 (0-4)
Plantago maritima	28	0.6 (0-4)	39	0.8 (0-4)
Deschampsia cespitosa	17	0.3 (0-4)	11	0.3 (0-3)
Hordeum brachyantherum	14	0.2 (0-2)	14	0.4 (0-5)
Spergularia canadensis	11	0.2 (0-3)	39	0.7 (0-5)
4. *Hordeum brachyantherum*	84	2.1 (0-5)	85	2.5 (0.5)
Agrostis alba	61	1.3 (0-4)	63	2.2 (0-5)
Deschampsia cespitosa	55	1.7 (0-5)	61	2.4 (0.5)
Potentilla pacifica	52	1.2 (0-4)	63	2.0 (0-5)
Stellaria humifusa	52	0.8 (0-4)	71	2.3 (0-5)
Triglochin maritimum	42	0.8 (0-3)	71	1.9 (0-4)
Glaux maritima	39	0.5 (0-2)	51	1.1 (0-4)
Plantago maritima	39	0.7 (0-3)	54	1.1 (0-4)
Festuca rubra	32	0.3 (0-1)	17	0.3 (0-2)
Salicornia virginica	23	0.4 (0-4)	15	0.3 (0-4)
Puccinellia pumila	19	0.3 (0-3)	17	0.6 (0-5)
Atriplex patula	10	0.1 (0-1)	5	0.1 (0-2)
Carex lyngbyei	6	0.1 (0-1)	49	1.6 (0-5)
5. *Elymus mollis*	89	3.9 (0-5)	100	4.1 (2-5)
Hordeum brachyantherum	33	0.6 (0-3)	70	2.0 (0-4)
Deschampsia cespitosa	33	1.1 (0-4)	30	0.8 (0-5)
Festuca rubra	33	0.3 (0-1)	—	—
Triglochin maritimum	22	0.3 (0-2)	—	—
Agrostis alba	11	0.6 (0-5)	30	1.3 (0-5)
Poa pratensis	11	0.1 (0-1)	—	—
Salicornia virginica	11	0.2 (0-2)	10	0.2 (0-2)
Plantago maritima	11	0.3 (0-3)	20	0.5 (0-3)
Potentilla pacifica	11	0.1 (0-1)	30	0.5 (0-2)
Puccinellia pumila	11	0.2 (0-2)	—	—
Atriplex patula	11	0.1 (0-1)	20	0.3 (0-2)
Holcus lanatus	—	—	10	0.2 (0-2)
Stellaria humifusa	—	—	10	0.2 (0-2)
Spergularia canadensis	—	—	10	0.1 (0-1)
Cochlearia officinalis	—	—	10	0.1 (0-1)
Sonchus uliginosus	—	—	10	0.2 (0-2)
Vicia gigantea	—	—	10	0.2 (0-2)

[1]Frequency ≥ 10%. Other species recorded with less than 10% frequency include *Cerastium vulgatum, Fritillaria camschatcensis, Honkenya peploides, Hypochaeris radicata, Poa annua,* and *Puccinellia nuttalliana.*

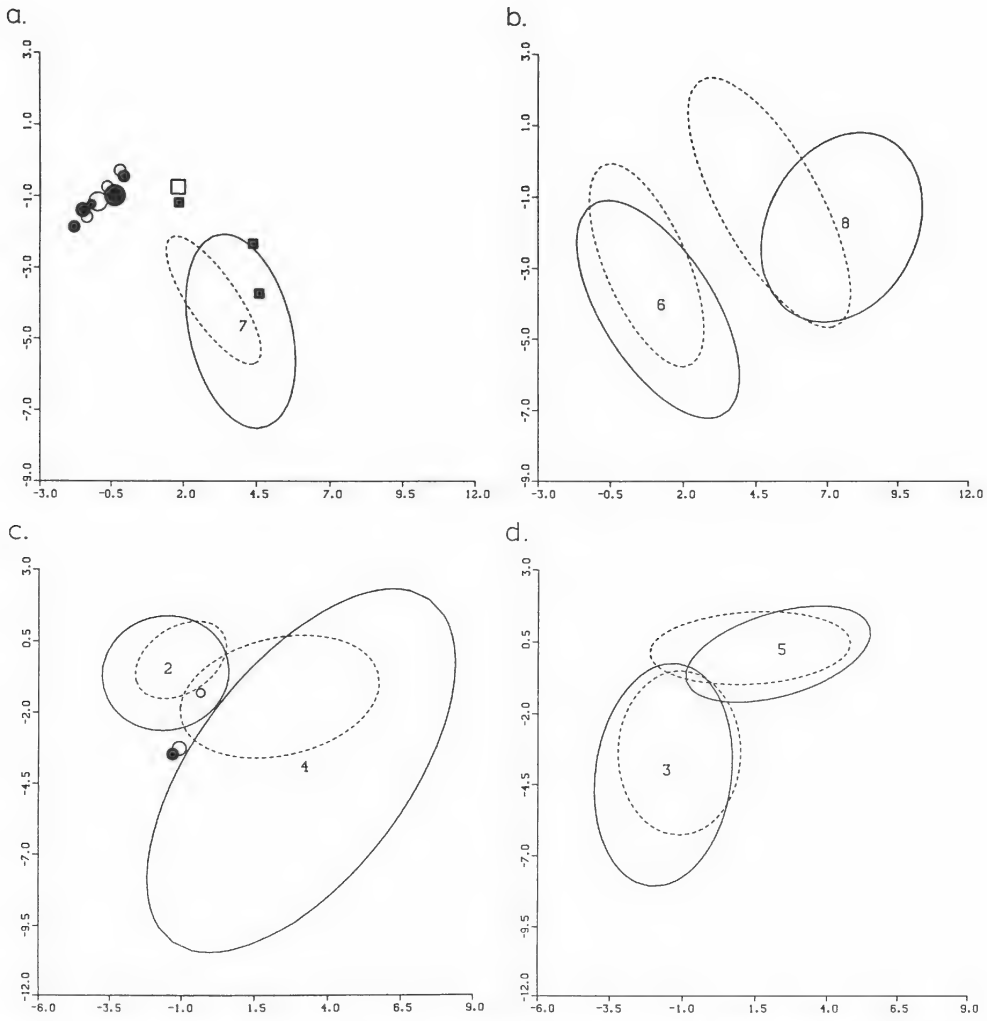

Figure 2. Changes in plant communities of the undyked (a,b) and dyked (c,d) areas at the Kokish marsh as shown by locational shifts in 95 percent confidence ellipses in the plane of the first two PCA axes. The single PCA's for each area are shown in two separate graphs to avoid cluttering of symbols. The first two PCA axes explain 59 percent of the variance in the undyked area and 42 percent of the variance in the dyked area. Broken outlines (1984 data); solid outlines (1986 data). Communities with small sample sizes are shown by the locations of separate quadrats: (a) undyked community 1 in 1984 and 1986, open and closed circles, respectively; undyked community 5 in 1984 and 1986, open and closed squares, respectively; (c) dyked community 1 in 1984 and 1986, open and closed circles, respectively. Numbers in ellipses refer to communities described in Table 2 and Figure 1.

The greatest changes are evident in undyked community 8, and dyked community 4. Both are mixed grass-forb "high marsh" types exhibiting moderate to substantial increases in species cover over the two year period (Table 2).

The correlations of PCA axes I and II from separate analyses of the 1984 and 1986 data allowed further comparison of the dyked and undyked areas (Table 3). The dyked area correlations were lower (0.47, 0.36) than those in the

TABLE 3. Correlations between principal components analysis (PCA) axis scores for the 1984 and 1986 data. The lower correlations in the dyked area suggest that a greater degree of vegetation change has occurred there than in the undyked area.

	PCA axes	
	I	II
Dyked area	0.47	0.36
Undyked area	0.83	0.52

undyked area (0.83, 0.52), suggesting that greater vegetation change had occurred in the dyked area.

Environmental change

Based on observations in the field during the early stages of tidal inundation on 22 July 1986, water began entering the dyked area through the original channel in the seaward portion of the dyke. Not until a considerable amount of saline water (22 ppt) had entered through that channel did river water (2 ppt) begin entering through the breach. Evidently, the breach channel was not deep enough to allow earlier entry of river water. After mixing, only a slight decrease in water salinity in the dyked area was observed (20 ppt).

The results of the soil salinity and organic matter analyses are given in Table 4. The salinity of the dyked area soil samples had not decreased over the years and remained twice as high as the salinity of soils in the undyked area. The higher percent organic content of the dyked area soils, noted by Bradfield and Campbell (1986) for the 1984 and 1985 samples, was also evident in the 1986 samples.

The dyked marsh at the Kokish also occurs at higher elevations than the undyked marsh (Bradfield and Campbell 1986). This contrasts with reports from other studies (Eilers 1980, Mitchell 1982, Taylor 1983) where the area behind the dykes had subsided. The subsidence noted elsewhere could be due to water loss and shrinkage of dyked area soils, or to different land use practices (e.g. compaction from livestock and equipment). No soil compaction was noted at the Kokish marsh and the high precipitation would tend to offset soil drying and shrinkage.

The lack of decline in salinity of the dyked area soils at the Kokish marsh could explain why the vegetation has not changed substantially. In order to lower the salinity in the dyked area the breach channel would have to be deepened to allow fresh water to enter the area sooner on a rising tide. However, it is uncertain whether any effective lowering of salinity levels could be achieved so long as seawater continues to enter through the original channel. Even if salinity were lowered it would be difficult to predict the eventual species composition. Species such as *Carex lyngbyei* may dominate for a while, but since the dyked area may be increasing in elevation owing to a lack of tidal flushing, the expansion of forest margin species into the high marsh seems a likely outcome.

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TABLE 4. Average organic matter and electrical conductivity for the dyked and undyked areas in 1984, 1985, and 1986. Standard deviations are given in parentheses.

Location	Year	Sample Size	Average organic matter (%)	Average electrical conductivity (mmho/cm)
Dyked Area	1984	24	38.1 (14.7)	33.2 (10.7)
	1985	28	31.8 (37.4)	58.0 (21.0)
	1986	32	37.4 (13.8)	39.9 (12.8)
Undyked Area	1984	24	6.2 (4.1)	12.1 (8.9)
	1985	28	9.9 (6.9)	20.1 (6.4)
	1986	32	7.9 (7.4)	22.2 (6.6)

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Use of Cover Types and Survival of Ring-necked Pheasant Broods

Abstract

Survival of young ring-necked pheasants (*Phasianus colchicus*) depends in part upon the habitat they use. However, little was known about the relation between habitat use and brood survival. Cover types used by broods of ring-necked pheasants were compared between broods that survived and those that perished for three time periods (hatching, 1-7 days of age, and 8-44 days of age). Survival of broods was related to cover types and, in some cover types, survival was a function of the age of the brood. Among five cover types, grains fields provided the most secure hatching and early brooding (1-7 days) cover. Strip vegetation was the least secure cover for hatching but was used frequently by broods that survived during days 8-44. Although pheasant broods used an array of cover types, survival was related to the frequency of use and timing of when these cover types were used.

Introduction

Deficiencies in nesting habitat often have been described as limiting factors to pheasant populations (Trautman 1960, Leite 1971, Guthery *et al.* 1980). However, as Warner (1984) suggested, mortality of young may contribute equally as a limiting factor. Although habitats used by pheasant broods have been described for areas throughout their range (Hanson and Labisky 1964, Hanson and Progulske 1973, Gates and Hale 1974, Warner 1979), little information is available regarding the relationship between brood survival and habitat use. In this study we tested for differences in the use of cover types by broods that survived and those that perished during three periods of brooding.

Methods

Two areas, representative of the land-use practices and crops grown in the Willamette Valley with similar proportions of cover types, were used for this study. The Baskett Slough area, 1049 ha, included portions of the Baskett Slough National Wildlife Refuge and adjacent private land and was located 20 km north of Monmouth, Polk County, Oregon. The Luckiamute area, 1514 ha, was located along the Luckiamute River, 8 km south of Monmouth, Polk County, Oregon.

During April and May of four consecutive years (1980-83), 468 captively propogated hen pheasants were equipped with radio transmitters and released on the study areas to evaluate their survival, reproduction, and habitat use (Meyers 1983, Castillo *et al.* 1984, Haensly 1984, Haensly *et al.* 1985). Types of propagated pheasants, rearing techniques, radio equipment used, and release methods were described in Haensly *et al.* (1985).

Although the study areas supported only low densities of wild pheasants, nesting and brooding cover were abundantly available. Likely, wild pheasant populations were not limited by availability of breeding habitat but by winter cover as suggested by Jarvis and Simpson (1978). Consequently, there was a surplus of breeding habitat available for pheasants as crops and natural vegetation matured in the spring.

The 468 hens released in this study initiated 224 nests from which 97 broods hatched (mid-May to early-August). For the purpose of this study it was assumed that the relative influence of cover types on brood survival determined for broods which were produced from captively

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propagated hens was similar for broods of wild hens, although actual survival rates may differ between broods of wild and captively reared hens. Previous work (Meyers 1983) indicated that similar numbers of broods hatched and survived on Baskett Slough and on Luckiamute and that similar cover types were available for brooding on the two areas throughout the study period. Consequently, brood data from the two study areas for the 4 years were combined to provide a statistically reliable sample. Broods were monitored biweekly (719 locations) from hatching until all chicks were lost or until hens were captured and transmitters were removed (predetermined date based on the expected longevity of batteries used in the transmitting units). We found it difficult to obtain accurate counts of chicks during the first several weeks after hatching without excessive disturbance of birds, and mixing of individuals among older broods further impeded accurate counts. Other researchers reported similar difficulties in obtaining accurate brood counts (Baskett 1941, Gates and Hale 1975). Therefore, we addressed survival (at least 1 chick alive) and loss of broods rather than of individuals.

Broods were monitored randomly during the day. Previous work on these study areas (Meyers 1983) indicated there were no differences in cover types used by broods among three day-time periods (morning, mid-day, and afternoon). Hatching cover was defined as the cover in which nests were located (determined by locating hens with radio-telemetry prior to hatching). Other brood locations were determined initially by triangulation to prevent observer influences on habitat use by broods; we then verified (sight or sound) that at least one chick accompanied the hen. If a brood was suspected of being lost or abandoned the monitoring continued for at least 2 weeks to verify that all chicks were gone.

When broods were located, the habitat in which they occurred was classified into one of the following cover types (percentages shown in parentheses):

1) Grain fields (37% of total): wheat (26%), oats (7%), barley (4%).
2) Strip vegetation (3% of total): fence rows, roadsides, and ditch banks.
3) Seed grass (26% of total): fescue (21%), ryegrass (3%), and sudan (2%).
4) Grassland (13% of total): pastures (9%) and uncultivated grasslands (4%).
5) Miscellaneous (21% of total): legumes (5%), mint (3%), vegetable crops (2%), tree/shrubs (2%), orchards (1%), and other (8%).

Comparisons of relative frequencies of cover types used by broods that survived and those that perished were made for three time periods:

1) Hatching—Cover types in which broods hatched were compared between broods that survived the first week and those that perished within 7 days after hatching.
2) Days 1-7—Cover types used by broods during the first week after hatching were compared between broods that survived this time and those that perished.
3) Days 8-44—Cover types used by broods during days 8-44 were compared between broods that survived through this period (i.e. >45 days) and those broods that perished during this time.

These time intervals were selected because results of Gates and Hale (1975) indicated that highest chick loss occurred during the first week after hatching and preliminary results from the present study revealed that among all broods that were lost ($n=52$), one-half perished within the first 7 days after hatching and the remainder were lost from days 8-44. All broods that survived >45 days ($n=28$) were alive when monitoring ended (mean age $=66$ days). The remaining 17 broods were alive but were <40 days of age when the study was terminated for radio recovery. Other researchers have also documented that broods reached a minimum size at about 6 to 8 weeks of age (Baskett 1941, Gates and Hale 1975).

Chi-square contingency tables (Snedecor and Cochran 1967) were used to test frequencies of occurrence among the five cover types and to compare use of specific cover types to use of all other cover types combined within a period.

Hatching cover

Cover types in which broods hatched differed ($\chi^2 = 17.6$, 4 d.f., $P < 0.01$) between broods that survived during the first week and those that perished (Table 1). Broods that survived the first week more frequently ($\chi^2 = 11.3$, 1 d.f., $P < 0.01$) hatched in grain fields (55%) than broods that perished (15%). Contrastingly, 35 percent

TABLE 1. Use of cover types by broods that survived and those that perished for three time periods, western Oregon, 1980-1983.

	Cover type used (%)[a]					
	Hatching		Days 1-7		Days 8-44	
	Broods that perished in ≤7 days (n=26;26)[b]	Broods surviving ≥8 days (n=67;67)	Broods that perished in ≤7 days (n=26;27)	Broods surviving ≥8 days (n=70;130)	Broods that perished between 8-44 days (n=26;94)	Broods surviving ≥45 days (n=28;277)
Grain fields	15	55**	15	52**	44	40
Strip vegetation	35	8**	11	4	5	15*
Seed grasses	27	15	19	18	16	7*
Grassland	16	16	37	15*	30	30
Miscellaneous	8	6	19	11	5	8

[a]Distribution of percentages among the 5 cover types were significantly different between those broods that survived and those that did not for each period. Significant individual comparisons within a time period are shown with * ($P < 0.05$) and ** ($P < 0.01$).

[b]Sample size (number of broods; number of locations).

of the broods that perished within the first week hatched in strips, but only 8% of those that survived hatched in strips ($\chi^2 = 8.8$, 1 d.f., $P < 0.01$). In addition, broods that hatched in grain fields survived longer ($\bar{x} = 35.6$ days) than broods hatched in strip vegetation ($\bar{x} = 13.7$ days). There were no differences in use of the other three cover types between broods that perished and those that survived.

Days 1-7

Use of cover types during the first week after hatching differed ($\chi^2 = 16.3$, 4 d.f., $P < 0.01$) between broods that survived and those that perished during this time. Use of grain fields was greater ($\chi^2 = 11.3$, 1 d.f., $P < 0.01$) among broods that survived (52% of locations) than among those that perished (15%) during the first week (Table 1). Broods that survived ($\chi^2 = 5.5$, 1 d.f., $P < 0.05$) were found in grassland cover less frequently than broods that perished (15% and 37% of locations, respectively). Use of other cover types during this period was not different between broods that survived and those that perished.

Relative use of cover types during days 1-7 was virtually identical to proportions of cover types in which broods hatched for those broods that survived the first week. Although broods that perished within the first week seemingly made greater use of grassland and miscellaneous cover types and reduced use of strip cover after hatching, these differences were not statistically significant.

Days 8-44

Cover types were used in different proportions ($\chi^2 = 14.7$, 4 d.f., $P < 0.01$) between broods that survived during days 8-44 and those that were lost during days 8-44. Broods that survived made 3X greater use of strips ($\chi^2 = 5.3$, 1 d.f., $P < 0.5$) than broods that perished during days 8-44 (Table 1). Use of seed grass cover was less ($\chi^2 = 5.9$, 1 d.f., $P < 0.05$) among broods that survived (7%) than among those that were lost (16%).

Broods that survived used the 5 cover types in different proportions ($\chi^2 = 18.4$, 4 d.f., $P < 0.01$) during days 8-44 compared to days 1-7. There was no difference in use of cover types between days 8-44 and days 1-7 for broods that perished during this time.

Discussion

We inferred from the results of this study that survival of broods was related to habitats used, including those cover types in which broods

hatched. Grain fields apparently provided the most secure hatching (also see Haensly *et al.* 1987) and early brooding cover. Use of grain fields was not different, however, during days 8-44 between broods that survived and those that perished; both groups of broods made greatest use of grain fields during this period. Unharvested grain fields provided dense overhead cover and efficient lanes for travel and escape. Harvested fields supplied an abundant source of food and cover because, in many instances, fields were left with approximately 0.5 m of stubble and broods continued to use these fields after harvest. Warner *et al.* (1984) likewise noted that grain fields were "prime pheasant brood habitat."

Strip vegetation, although preferentially selected by hens for nesting (Meyers 1983), seemingly was not secure cover for young broods. Limited capacity of young chicks to escape predators possibly decreased their chances of survival in strips. Haensly (1984) documented high rates of nest loss and hen mortality by predators in strip habitats. Among older broods (days 8-44), those that survived made greater use of strips than broods that perished. Strip cover apparently was beneficial to the survival of poults, which have better abilities to escape predators than do chicks. R. E. Warner (pers. comm.) suggested that the increased use of strip cover with age often resulted from increased mobility and greater use of edge habitats.

Seed grasses after harvest provided little cover for pheasant broods. These crops were harvested by cutting to nearly ground level during June and the fields were burned in late summer. The resultant habitat changes may account for loss of broods that made the greatest use of seed grasses during days 8-44 or mortality may have been induced by birds attempting to move from harvested grass fields. Grassland cover type, although used identically by broods that survived and those that perished for hatching (16%) and during days 8-44 (30%), apparently was not secure cover for broods from days 1-7. We have no explanation for this difference. Lastly, use of the miscellaneous cover types appeared unrelated to survival of broods.

This work and that of others (Hanson and Labisky 1964, Hanson and Progulske 1973, Warner 1984) demonstrated that pheasant broods use an array of cover types, which in western Oregon includes a variety of small grains, grasslands, seed grasses, and strip vegetation. Our results suggested, however, that survival of broods is related to cover types used and, in some cover types, survival is a function of the age of broods.

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Distribution and Diet of Sea-run Cutthroat Trout Captured In and Adjacent to the Columbia River Plume, May-July 1980.

Abstract

Cutthroat interact with other migrating juvenile and adult salmonids within the Columbia River plume. By collecting basic life history information, we broaden our knowledge of both cutthroat trout migrations within the Columbia River plume and how they interact as a predator on juvenile fish and zooplankton. To study these fish, sea-run cutthroat trout were collected in marine waters within and adjacent to the mouth of the Columbia River plume between Tillamook Bay, Oregon and Copalis Head, Washington. A total of 232 purse seine sets were made during three cruises from late May to early September, 1980. Age, size, and diet were examined. Cutthroat trout were found to range farther offshore than previously reported. They were captured within the Columbia River plume as far as 31 km offshore. Six age groups, 2 to 7 years, were identified. Fifty percent of the aged cutthroat were of hatchery origin. Stomach analysis from the May-June cruise revealed cutthroat trout feed on a wide variety of food items, with fish and mysids predominant.

Introduction

There are few studies of sea-run cutthroat trout, *Salmo clarki clarki,* in marine coastal waters. Information on the distribution and movement in saltwater has been presented by Jones (1974, 1975, 1976) for Alaska, and Giger (1972) for Oregon. Additionally, limited information has been reported for cutthroat stocks within the lower Columbia River and plume (Sumner 1972, Fisher and Pearcy 1985). Food items of cutthroat trout in coastal marine waters have been reported by Clemens and Wilby (1946), Haig-Brown (1947), Armstrong (1971), Giger (1972), Sumner (1972), Simenstad and Kinney (1978), and Brodeur *et al.* (1987).

Historically, cutthroat trout populations have been relatively small when compared to other salmonids. Royal (1972) wrote that historic steelhead, *S. gairdneri,* populations in Washington comprised two to three percent of the total anadromous salmonid populations and that cutthroat trout population levels were thought to be much less than that of steelhead populations.

The purpose of this study was to document distribution, age, size, and diet of adult sea-run cutthroat trout captured within and adjacent to the Columbia River plume. The plume is defined by the freshwater dilution of the coastal waters adjacent to the Columbia River. The study survey area was located within the inner plume marked by the 27 o/oo isohaline. The outer bounds of the plume, defined by the 32.5 o/oo isohaline (Barnes *et al.* 1972), was not encompassed. Fish were collected as part of a more comprehensive study by the National Marine Fisheries Service to define the marine migrational patterns of juvenile salmonids emigrating from the Columbia River estuary (Miller *et al.* 1983).

Methods

A total of 232 sets were made along ten east-west sampling transects which were established along the Pacific Northwest coast from Tillamook Bay, Oregon, to Copalis Head, Washington (Figure 1). Each transect contained five sampling stations; the first located at the 30 m depth contour, with the others extending seaward at 8 km intervals. Purse seining was conducted during three periods: 27 May-7 June, 4-15 July, and 28 August-8 September 1980.

The sampling net was a 495 x 30 m purse seine that was assumed to fish approximately 24 m deep based on its construction (J. Jurkovitch, Gear Specialist, NMFS, Northwest and Alaska Fisheries Center, Seattle, Washington, personal communication February 1981).

All fish collected were anesthetized with benzocaine, counted by species, measured to fork

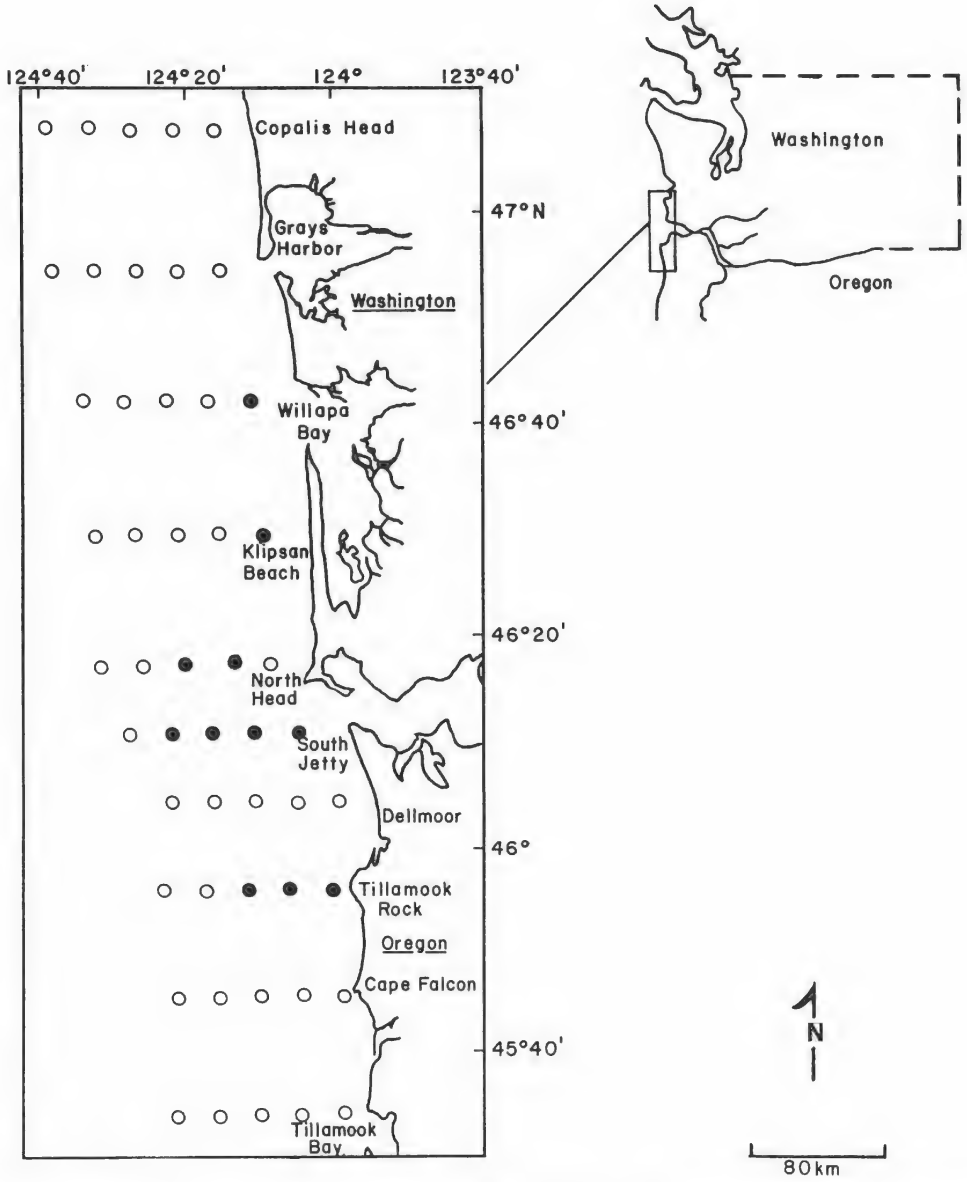

Figure 1. Location of transect stations (circled areas) for off shore marine purse seining of salmonids along the Oregon and Washington coast, 1980. Darkened circles are areas of cutthroat captures.

length and examined for identifying marks. Stomachs (esophagus to the pyloric caeca) were removed and preserved with buffered 10 percent formaldehyde solution in individual vials for later analysis. Processing of the stomachs was as described by Cailliet (1977). Organisms were identified to the lowest practical taxon.

Scales were collected for age determination. Methods similar to Narver and Withler (1971) were used to age cutthroat scales. Briefly, age was assigned using a chronological arrangement (i.e., 2.+F+S+) of arabic numerals to designate the number of consecutive winters in freshwater. A period (.) indicates the point of initial saltwater entry. Each plus sign (+) denotes saltwater residence less than one year in duration. Spawning checks are designated with a captial letter "S," where a "+S" denotes one chronological year. Not all returning adult sea-run cutthroat spawn on their first re-entry to freshwater from saltwater. We define a freshwater re-entry from saltwater and temporary residence with no spawning before migrating back to saltwater (as evident by no scale resorption) as a "feeding run" and we designate this "feeding run" with the letter "F." An "+F" indicates one chronological year. Therefore, a fish aged 2.+F+S+ would have spent two winters in freshwater after

Figure 2. Sea-run cutthroat trout scale with two years of freshwater growth. Marine growth and "feeding" check (+F) followed by additional marine growth and a spawning check (+S) follow the freshwater growth. The last scale check (+S) is followed by marine growth (+) for a total age of 4+.

hatching, another summer period at sea, freshwater re-entry and return to the ocean, freshwater re-entry spawning, and was captured during its third saltwater migration at an age of 4+ (Figure 2). All age 1 fish were assumed to be of hatchery origin.

Results and Discussion

Distribution

Cutthroat were collected along the coast from Tillamook Bay, Oregon, to Willapa Bay, Washington (Table 1). Catches were made 3.0 to 31.5 km offshore, over bottom depths ranging from 30 to 134 m. All of the cutthroat trout collected were captured within the Columbia River plume. In 1978 and 1979, no cutthroat trout were captured during sampling with a 305 x 11 m purse seine inside the 30 m depth contour from May to September (Dawley *et al.* 1978, 1979, 1980).

Little information exists regarding the distance offshore that cutthroat trout have been captured. Haig-Brown (1947) reported adult cutthroat range off shore as far as 7 km from the mouth of the Nimpkish River on Vancouver Island, Canada. Sumner (1972) also mentioned sport anglers harvesting cutthroat trout offshore at a similar distance. The greatest offshore distance for cutthroat trout captured during our study was in the river plume (31.5 km) off the South Jetty at the mouth of the Columbia River. This distance from shore was surprising, since existing evidence suggests that sea-run cutthroat trout avoid traveling in large open bodies of water and tend to follow shorelines (Jones 1976).

This suggests that substantial numbers of cutthroat might be found within the influence of a large riverine plume. Sumner (1972) proposed that cutthroat originating in the Columbia River basin might go out some distance from the coast while remaining within the Columbia plume. This observation agrees with our findings. The offshore distance cutthroat migrate may depend on the Columbia River outflow during their migration to saltwater. Maximum river flows for the Columbia River occur during May, June, and July (Neal 1972). Columbia River sea-run cutthroat emigrate to saltwater in April and early May (Dawley *et al.* 1978, 1979, 1980). Besides the influence of maximum flows, cutthroat might drift with a current while feeding and be relocated to other areas. Prevailing currents during May and June may move cutthroat to areas farther offshore and away from the mouth of the river. Giger (1972) noted ocean currents could redistribute cutthroat to other areas thereby increasing the occurrence of straying to other rivers along the Oregon coast. This might explain marked cutthroat trout stocked into the Alsea River, Oregon, being captured in the estuary of the Siuslaw River, Oregon, in 1967 (Sumner 1972).

Table 1. Location of cutthroat trout caught off Oregon and Washington, May-July 1980.

Date	Number caught	Transect	Station	Distance offshore (km)	Water depth (m)
30 May	1	Tillamook Rock	1	3.0	42
30 May	2	Tillamook Rock	3	17.6	112
31 May	2	Tillamook Rock	2	11.1	84
6 June	2	Klipsan Beach	1	8.2	30
7 June	4	South Jetty	2	16.7	60
7 June	5	South Jetty	3	23.6	101
7 June	1	South Jetty	4	31.5	117
12 July	1	Willapa Bay	1	8.3	30
14 July	1	South Jetty	1	9.3	30
14 July	9	South Jetty	2	16.7	60
14 July	3	South Jetty	3	23.6	101
15 July	1	North Head	2	14.4	71
15 July	2	North Head	3	21.8	128

No correlations between temperatures, salinities, and fish abundance were found. At sites where cutthroat trout were collected, surface water temperatures ranged from 12.2 to 16.4° C, and surface salinities from 26.7 to 28.2 o/oo.

Cutthroat trout were captured only during May-June (17) and July (17). None were caught during the August-September cruise. Cutthroat have been reported to re-enter the lower Columbia River estuary in early June (Loch 1982). This return timing is similar to that observed by Sumner (1972) and Giger (1972) for the Nestucca and Alsea estuaries in Oregon, respectively. Cutthroat have been reported to move into the upper Columbia River estuary in early July (Dawley *et al.* 1978, 1979, 1980). Dawley *et al.* also reported a lull in the upstream movement of cutthroat in June. Differences between immigration observations by Loch (1982) and Dawley *et al.* (1978, 1979, 1980) are due to their different sampling locations within the Columbia River estuary. A distance of about 60 km separated the two locations. We feel cutthroat re-entering from saltwater to freshwater remain and feed for a short period of time in the lower and mid-Columbia River estuary before moving farther up stream. This is in conflict with Giger (1972) who reported no feeding by cutthroat while on their migration from saltwater to freshwater. Instead, Giger (1972) believed cutthroat moved rapidly through estuaries in Oregon. In support of our hypothesis, Loch (1982) found adult cutthroat actively feeding on Pacific herring, *Clupea harengus pallasi* and bay shrimp, *Crangon franciscorum* in the lower Columbia River estuary. This suggests that at least some adult cutthroat do not directly move into freshwater zones on return from saltwater but actively feed within the marine and estuarine zones.

Ages of 18 of the 34 cutthroat trout collected revealed six age groups ranging from 2 to 7 total years (Table 2). Interestingly, only fifty percent of the aged fish were of wild origin. Many lower Columbia River tributaries have been planted with sea-run cutthroat trout since 1957. Plants in Washington have totaled as much as 280,000 cutthroat smolts (Crawford *et al.* 1981). Wild fish were generally older and larger than hatchery cutthroat (Table 2).

All hatchery cutthroat were collected within the Columbia River plume. This information provides fish managers with some of the first evidence that hatchery cutthroat do migrate out into the Columbia River plume where they may compete with other salmonids for food or be preyed upon.

The trout caught in July were very similar in size (mean 301 mm with a range from 240 to

TABLE 2. Age and length of hatchery and wild cutthroat trout sampled by marine purse seine operations adjacent to the mouth of the Columbia River, 1980.

Stock	Numbers captured	Age[1]	Mean fork length ± tSE (mm)[2]	Percentage of total
Hatchery	7	1.+	260.3 ± 17.5	77.8
	2	1.+F+	298.0 ± 226.4	22.2
	9			100.0
Wild	6	2.+	287.7 ± 43.5	66.7
	1	2.+S+	365.0 ———	11.1
	1	2.+F+S+	415.0 ———	11.1
	1	3.+S+S+S+	470.0 ———	11.1
	9			100.0

[1]. = initial entry to seawater
F = freshwater residence, did not spawn
S = spawned upon re-entry to freshwater from seawater
+ = subsequent marine excursion
[2]$\propto$ = 0.05

345 mm) to those captured earlier in the May-June cruise (mean 296 mm with a range from 240 mm to 470 mm).

Diet

Although cutthroat trout fed on a variety of prey items during May and June, they were mainly piscivorous. Of the 17 stomachs examined from the May-June cruises, principal prey items were fish, mysids, brachyuran crab megalops, and euphausiids. By weight, fish were the most dominant food item found in the stomach samples, composing 82.7% of the total food biomass (Table 3). Juvenile cabezon, *Scorpaenichthys marmoratus,* and Pacific sand lance, *Ammodytes hexapterus,* were common species found in stomachs. Other researchers have also found that cutthroat prey primarily on fish. Off the Oregon and Washington coast, Brodeur *et al.* (1987) reported cutthroat to feed on juvenile and adult northern anchovies, *Engraulis mordax,* juvenile kelp greenlings, *Hexagrammus decagrammus,* and rockfishes, *Sebastes* spp. Sand lance and Pacific herring were mentioned by Haig-Brown (1947) as prey of cutthroat off the mouth of several Vancouver Island streams, British Columbia.

Interestingly, at a time when large numbers of juvenile salmonids were actively migrating to saltwater, no juvenile salmonids were found in our cutthroat stomach samples. Miller *et al.* (1983) reported large numbers of both juvenile chinook, *Oncorhynchus tshawytscha,* and coho, *O. kisutch,* salmon in areas within and adjacent to the Columbia River plume at a time when we were collecting adult cutthroat. Unlike our findings, Brodeur *et al.* (1987) found juvenile salmon in stomach samples from offshore captures of Oregon and Washington cutthroat adults in both 1981 and 1984. Clemens and Wilby (1946) mentioned salmonids as food for cutthroat in some Canadian marine areas and Armstrong (1971) found juvenile salmon in stomachs of cutthroat in the coastal waters of Alaska.

TABLE 3. Stomach contents (prey) of 17 coastal cutthroat trout caught off Oregon and Washington, May-June 1980.

Prey	Number of prey	Weight of prey (g)	Occurrence[1] (%)	Composition (%)	
				Number[2]	Weight[3]
Northern anchovy *Engraulis mordax*	1	10.97	5.88	1.96	34.07
Cabezon *Scorpaenichthys marmoratus*	2	2.97	11.76	3.92	9.22
Pacific sand lance *Ammodytes hexapterus*	1	1.17	5.88	1.96	3.64
Surf perch (Embiotocidae unidentified)	1	2.08	5.88	1.96	6.47
Crab meglops	6	0.31	17.65	11.76	0.95
Euphausiacea	1	<0.01	5.88	1.96	0.01
Mysidacea (unidentified)	31	0.55	11.76	60.78	1.71
Neomysis kadiakensis	8	0.25	5.88	15.69	0.79
Unidentified digested fish	—	11.51	47.06	——	35.73
Unidentified digested other material	—	2.39	70.59	——	7.42
Empty	—	——	11.76	——	——

[1]Number of occurrences/total number of stomachs examined.
[2]Number of prey item/total number of prey.
[3]Weight of prey item/total weight of prey.

Although a major portion of the biomass in the stomach samples from cutthroat consisted of fish, numerically mysids were a dominant food item (Table 3). Both Clemens and Wilby (1946) and Haig-Brown (1947) mention crustaceans as food items, neither define what species of crustaceans were consumed. Simenstad and Kinney (1978) found gammarid amphipods to be the dominant prey item followed by sphaeromatid isopods, cumaceans, and callianassid shrimp in cutthroat trout captured in Hood Canal, Washington. Brodeur *et al.* (1987) found euphausiids and insects numerically dominant in stomachs collected in waters off Oregon and Washington in 1984. Because cutthroat tend to be opportunistic, feeding on what is available, differences observed in our samples from those of other researchers may be due to seasonal occurrence and abundance of cutthroat prey items.

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Helicopter Immobilization of Elk in Southcentral Washington

Abstract

Free-ranging elk (*Cervus elaphus*) are commonly immobilized for research or management by rifle-fired darts shot from a helicopter. Compounds used for this purpose have included succinylcholine chloride (succinylcholine), etorphine hydrochloride (etorphine), and xylazine hydrochloride (xylazine). To assess the efficacy of various immobilizing drugs used in helicopter applications, we darted 38 elk from a helicopter on the Arid Lands Ecology Reserve, Washington from 1983 to 1987. We used either succinylcholine, etorphine hydrochloride, or xylazine hydrochloride as primary immobilants. Unsuccessful immobilizations were most common in elk darted with succinylcholine. Induction times were similar in elk darted with xylazine and etorphine and shortest in elk darted with succinylcholine. Yohimbine was used to reverse xylazine immobilizations. The use of xylazine and yohimbine provides an efficient, cost-effective alternative to etorphine, diprenorphine immobilization and reversal in elk while increasing handler safety. Etorphine appeared to be the best immobilant when extended pain-producing procedures (such as surgical telemetry implantation) are planned because it induced the longest and deepest anesthesia. When the potential to lose contact with darted animals exists, we believe succinylcholine may be the preferred immobilant because of rapid, spontaneous recovery.

Introduction

Darting from a helicopter is a common method used to capture elk for research purposes in North America (Jessup 1982), but most published data on immobilizing elk concern darting animals in a trap (Coggins 1975, Amstrup *et al.* 1982, Meuleman *et al.* 1984). An animal's degree of excitation can have a major effect on dosage required for chemical immobilization (Fowler 1978). Elk darted from a helicopter experience elevated muscular and physiological activity prior to injection in comparison to elk darted in a trap. Thus, immobilization data specific to helicopter applications are needed. Although several compounds have been used to immobilize elk from a helicopter (Hebert *et al.* 1982), physiological variation between study populations has complicated a comparison of the efficacy of various compounds and dosages.

Between 1983 and 1987, we used three different compounds to immobilize wild elk from a single population on the Arid Lands Ecology Reserve in south-central Washington using a helicopter. In this paper, we report results of our immobilizing efforts using three traditional compounds (or combinations) and one new combination.

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Methods

Adult elk were darted from a Hughes 500C helicopter using a Palmer Cap-Chur® long-range projector (use of trade names does not imply endorsement by the authors or sponsoring agency). Elk were immobilized with either liquid succinylcholine chloride (Sucostrin®) (0.09-0.14 mg/kg), a combination of etorphine hydrochloride (M99®) and acepromazine maleate (Acepromazine®) (0.02-0.04 mg/kg:0.02-0.03 mg/kg), a combination of etorphine and xylazine hydrochloride (Rompun®) (0.01-0.02 mg/kg:0.35-0.55 mg/kg), or xylazine alone (1.4-1.5 mg/kg). Etorphine-induced immobilizations were reversed with diprenorphine hydrochloride (M50-50®) (2x M99 dose). Xylazine effects were reversed with yohimbine hydrochloride (Antagonil®) (0.15-0.20 mg/kg) whether xylazine was administered alone or in conjunct

with etorphine. Succinylcholine-immobilized elk recovered spontaneously.

Failed immobilizations were those in which darted elk did not become recumbent. We could not differentiate dart malfunction from dosage inadequacies. Elk darted with succinylcholine were followed for 30-35 min before the attempt was aborted. Elk darted with etorphine were monitored for approximately 90 min before an attempt was judged to have failed.

Induction times were compared using a Kruskal-Wallis test and non-parametric multiple comparisons (Conover 1971:231).

Costs per immobilized elk were calculated by adding drug costs to helicopter time. Helicopter time was calculated as induction times plus time used monitoring failed immobilizations (following darted elk until attempt was judged to have failed). We used a rate of $350/hr for helicopter costs. Time required to dart elk was assumed to be the same regardless of compound used and was not included in cost estimates. These costs do not represent the true costs of capturing an elk, since most helicopter time is spent flying to and from study areas and locating target animals. They do, however, represent relative costs associated with each immobilizing compound.

Results and Discussion

Thirty-eight elk were darted from a helicopter (Table 1). Failed immobilizations were most common in elk darted with succinylcholine (N = 24). Three failures were associated with one batch of succinylcholine and may represent degraded drug (100% of attempts with this batch), and one failure was probably due to a frozen dart. Regardless, the dependability of immobilizations using this compound was lowest. Succinylcholine is known to be degraded by exposure to light and heat (Fowler 1978). Only one failed immobilization occurred using etorphine (N = 11). None of the classic signs associated with etorphine induction were noted in this case, and we suspect dart malfunction. No failed immobilizations were noted in our use of xylazine alone (N = 3).

Induction times were significantly shorter in elk darted with succinylcholine than in elk darted with etorphine or xylazine ($P < 0.01$) (Table 1). Induction times were not significantly different between elk darted with etorphine or xylazine ($P > 0.25$). Elk darted with only xylazine became sedentary within 10 min even though they did not become recumbent for 15-20 min. One elk darted with xylazine became sternally-recumbent within 10 min but was not tractable for 40-60 min. The duration of immobilization averaged 36 min in succinylcholine-immobilized elk. The period of immobilization was controlled by antagonist administration when using etorphine and xylazine.

Our results with etorphine suggest that the total dose of additional tranquilizer may be more crucial to optimal immobilizations than the etorphine dose. Given volume restrictions in rifle-fired darts, we found it most effective to reduce etorphine volume while increasing xylazine volume. Four mg of etorphine were quite effective when coupled with 100-150 mg of xylazine. The temptation to assume that a maximum etorphine dose is critical to effective immobilization

TABLE 1. Results of helicopter darting on the Arid Lands Ecology Reserve, Washington, 1983-87. Values given are mean ± 1 SE (range).

Immobilant	Dose [mg/elk]	No. of Immobilizations		Induction (min)	Duration of Immobilization (min)	Reversal Agent	Time to Recovery (min)
		Succeeded	Failed (%)				
Succinylcholine	24.7 (23-26)	13	11(46)	8.7 ± 0.6 (5-12)	36.1 ± 6.1	none	—
Etorphine/ Acepromazine	6.3:4.5 (6-6.8)[a]	4	1(20)	37.8 ± 17.7 (12-90)	—	Diprenorphine	6.8 ± 2.6
Etorphine/ Xylazine	4.2:130 (3-5)	6	0	20.5 ± 3.1 (10-31)	—	Diprenorphine/ Yohimbine	9.4 ± 2.8
Xylazine	380 (350-400)	3	0	32.0 ± 15.4 (14-63)	—	Yohimbine	4.0 ± 1.2

[a]One elk required a second dose of 3.0 mg etorphine before it became tractable (total dose = 9.8 mg).

should be avoided. The shorter induction times associated with a liberal dose of xylazine reduced helicopter time and the risks of hyperthermia to etorphine-immobilized elk. Elk darted with etorphine/xylazine also tended to be more tractable than elk darted with etorphine/acepromazine. The heavy xylazine dose is especially favored since a xylazine reversal agent (yohimbine) has become available (application for FDA licensing has recently been submitted).

While our sample of elk darted with xylazine alone was small, results were consistent. Two of the three elk darted were large bulls; thus, this method appears to be promising even when darting large elk. Previously, delayed recovery detracted from the utility of xylazine-alone immobilization in elk. However, the availability of a xylazine antagonist now appears to eliminate this problem. Recovery following administration of yohimbine was dramatic and rapid. Elk typically stood on their initial attempt, and none returned to recumbency. Recovery tended to be more rapid and complete than that reported by Jessup *et al.* (1983) in mule deer (*Odocoileus hemionus*). One elk was seen four hours after immobilization approximately 11 km from the capture site, suggesting that re-narcosis did not occur. We obtained similar results with xylazine/yohimbine and etorphine/diprenorphine. However, drug costs and risks to crew from the immobilizing compound were reduced with xylazine (very low doses of etorphine can be fatal to humans [Parker and Haigh 1982]). The latter can be important since wildlife captures are often conducted in remote places, far from professional medical help.

We did not note any drug-related mortalities when using these compounds, and no post-capture complications were noted in elk immobilized during the study. Xylazine and etorphine appear to have a high Therapeutic Index (lethal dose/effective dose) in elk. Succinylcholine may produce apnea at high doses (Fowler 1978), but we recorded no instances at the doses we used.

The cost per immobilized elk was lowest using xylazine alone ($106/elk) and etorphine/xylazine ($153/elk), intermediate in elk darted with succinylcholine ($199/elk), and highest in elk darted with etorphine/acepromazine ($412/elk). Succinylcholine was the most inexpensive compound, but helicopter time associated with failed immobilizations inflated the cost per captured elk.

Based on our limited experience, we believe the use of xylazine and its antagonist, yohimbine, is a promising solution to maximizing immobilization efficiency and drug-related personnel safety, while minimizing the costs associated with darting elk from a helicopter. Etorphine is a useful compound when combined with xylazine, but clearly represents a substantial safety risk to darting crews. Etorphine is favored if surgical procedures are planned, since etorphine produces a more complete analgesia than xylazine. Succinylcholine has utility in helicopter applications when short inductions and downtimes are desired, although the experience is clearly more stressful to elk than immobilization with xylazine or etorphine. Succinylcholine may be particularly useful when darting elk in areas where loss of contact with darted animals is a distinct possibility. The rapid and spontaneous recovery of succinylcholine-immobilized elk would likely minimize the risk of mortality to elk which are darted but escape before they can be handled.

We did not note sex-specific dose differences with xylazine or etorphine. Since it is difficult to estimate weights of elk when they are running in front of a helicopter, it is more practical to load darts by total doses. We suggest a xylazine dose of 400 mg or a combined dose of 4-5 mg etorphine and 100-150 mg xylazine for either sex of adult elk when darting from a helicopter. The antagonists diprenorphine and yohimbine should be administered intravenously for the best effect and to avoid local tissue damage associated with large intramuscular injections. Bull elk seemed to require slightly larger doses of succinylcholine than cows. Our elk were in extremely good condition (average estimated weight = 255 kg). We recommend succinylcholine doses of 23-25 mg for cows and 25-27 mg for bulls in similar condition. Vials from at least 2 different, recent succinylcholine batches should be taken to the field. Loaded succinylcholine darts and spare vials should be kept cool and shielded from light.

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March 22-25, 1988
Southern Oregon State College
Ashland, Oregon

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Northwest Scientific Association

(Founded 1923)

The Northwest Scientific Association, an affiliate of the American Association for the Advancement of Science, is an association representative of the basic and applied sciences and of social sciences.

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NORTHWEST SCIENCE

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Sixty-first Annual Meeting
of the
Northwest Scientific Association
March 22-25, 1988
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REGISTRATION AND SPECIAL PUBLIC LECTURES

Registration:

The Registration Area is in the Science Building, Room 171. Signs and banners will guide you to the proper location. The Registration Area will be open from 3:00 p.m. to 8:30 p.m. on Tuesday, March 22, and will open again at 7:30 a.m. on Wednesday morning. Additional hours will be posted at the Registration Area.

It is recommended that you pick up your registration packets at the earliest possible time. Any information regarding last minute changes in the program or other events will be posted in the Registration Area.

Public Lecture:

The Program Coordinators of the NWSA Annual Meeting have arranged two lectures which the general public may attend. Tickets for these lectures are free to registered attendees (tickets will be in the registration packet). Those not registered to attend the Annual Meeting may purchase tickets at the Registration Area or at the door. Tickets are also free to anyone with a valid Southern Oregon State College identification card. The general public may purchase tickets at $3.00 each, $2.00 for seniors 65 and over.

The lectures are:

Tuesday: Berend Würsig of the University of California Marine Biology Station at Moss Landing, California, is an internationally-recognized authority on cetaceans. He will speak in Science Building, room 118 on *Tuesday evening, March 22, 1988, at 8:00 p.m.* His topic is "Dolphins: Patterns of Social Organization."

Wednesday: Meredith F. Small, a world authority on primates who is presently a member of the Department of Anthropology and the California Primate Center at the University of California, Davis, will speak in Science Building, room 118 at *7:00 p.m., Wednesday, March 23.* Her topic is "Female Primate Mating Strategies."

PROGRAM SCHEDULE

Tuesday, March 22:

3:30-8:30 p.m.	Registration, Science Building, room 171.
8:00 p.m.	Public Lecture: Berend Würsig, "Dolphins: Patterns of Social Organization," Science Building, room 118.

Wednesday, March 23:

7:15-11:00 a.m.	Registration, Science Building, room 171.
8:00-4:30 p.m.	Symposium I—Reforestation Knowledge and Management of Southwestern Oregon Forests: Past, Present, and Future. (Sponsored by FIR Project), Science Building, room 118.
7:00 p.m.	Public Lecture: Meredith Small, "Female Primate Mating Strategies," Science Building, room 118.
7:00 p.m.	Board Meeting, Stevenson Union Room 313.

Thursday, March 24:

8:00-10:00 a.m.	Registration, Science Building, room 171
9:00-4:00 p.m.	Botany Field Trip to Eight Dollar Mountain, Darlingtonia Bog in the Siskiyou Mountains. Box lunch included.
5:30-6:30 p.m.	No Host Social, Stevenson Union Rogue River Room.
6:30-9:30 p.m.	Banquet and Program, Stevenson Union Rogue River Room. Welcome: Dr. Joseph Cox, President, SOSC. Speaker: Prof. Leon Hunsaker, Meteorologist.

Contributed Paper Presentations:

8:00-4:50 p.m.	Forest Science (Science Building, room 118)
9:00-2:40 p.m.	Geology/Geography (Science Building, room 108)
8:00-1:20 p.m.	Zoology (Science Building, room 275)
2:00-3:00 p.m.	Science Education (Science Building, room 275)
1:00-2:40 p.m.	Environmental Sciences (Science Building, room 171)

Friday, March 25:

8:00-10:00 a.m.	Registration, Science Building, room 171.
8:00-4:30 p.m.	Symposium II—Natural History of the Siskiyou Mountains. Sponsored by the USDA Forest Service, Southwest Oregon Ecology Program (Science Building, room 108).
9:00-4:00 p.m.	Geology Field Trip to Siskiyou Mountains, Klamath River Canyon. Box lunch included.
12:00 noon	Business Meeting/Luncheon, Stevenson Union Rogue River Room.

Contributed Paper Presentations:

8:00-4:50 p.m.	Forest Science (Science Building, room 118)
8:00-3:00 p.m.	Botany (Science Building, room 275)

Wednesday, March 23, 1988
SYMPOSIUM I

Reforestation Knowledge and Management of Southwestern Oregon Forests: Past, Present, and Future

Sponsored by:
Forestry Intensified Research (FIR) Program,
College of Forestry, Oregon State University, Corvallis
Science Building, Room 118

8:00 a.m. **Reforestation Silviculture: Past, Present, and Future**

Introduction—Jack Walstad, FIR Program Leader.

Historical reforestation problems and the area's ecology—Don Minore, PNW, U.S. Forest Service, Corvallis, OR.

Genetics: What do we know and where do we go?—Robert Campbell, PNW, U.S. Forest Service, Corvallis, OR.

Seedlings and planting: the more things change. . .—Ole Helgerson, FIR Program, Oregon State University.

Silvicultural systems: where's the heat?—David McNabb, FIR Program, Oregon State University.

Weeds and trees: where are we now?—Michael Newton, Oregon State University.

10:00 a.m. BREAK—Questions on notecards from audience.

10:30 a.m. Panel discussion on reforestation silviculture.

11:30 a.m. LUNCH

1:00 p.m. **Reforestation Management and Information Needs**

Introduction—William Atkinson, Head, Department of Forest Engineering, Oregon State University.

The BLM perspective—David Jones, District Manager, Medford District, Bureau of Land Management.

The Forest Service perspective—Steve Deitemeyer, Supervisor, Rogue River National Forest.

The industry perspective—Charlie Brown, Fruit Grower's Supply Corporation, Hilt, CA.

Using information to resolve questions of policy and management—Tom Terry, Manager, Western Forestry Research, Weyerhaeuser Corporation, Centralia, WA.

3:00 p.m. BREAK—Questions on notecards from audience.

3:30 p.m. Panel discussion on reforestation management.

4:15 p.m. Summary and closing—William Atkinson.

Friday, March 25, 1988
SYMPOSIUM II

Natural History of the Siskiyou Mountains

Sponsored by:
USDA Forest Service, Southwest Oregon Ecology Program
Medford, Oregon
Science Building, Room 108

8:00 a.m.	Geologic Setting (plate tectonics and the major formations)—Mark Prchal
8:40 a.m.	Soils ecosystems (physical, chemical, and biological properties)—Mike Amaranthus
9:20 a.m.	Weather (extremes, norms, and fire weather)—Claude Curran
10:00 a.m.	BREAK
10:20 a.m.	Paleobotany and early botanical explorations—Frank Lang
11:00 a.m.	Fire history (history and role of fire in the ecosystem)—David Wheeler
11:40 a.m.	Vegetation of the Siskiyous (plant associations and environment)—Lisa McCrimmon
12:00 noon	LUNCH BREAK
1:00 p.m.	Rare and unique species of the Siskiyous—Joan Seevers
1:45 p.m.	Wildlife relationships—Lee Webb
2:30 p.m.	BREAK
2:45 p.m.	Options of integrated forest management—Mel Greenup
3:45 p.m.	Summary (ecosystem diversity and health)
4:30 p.m.	Session ends

CONTRIBUTED PAPER PRESENTATIONS
Thursday, March 24, 1988

Forest Science (Science Building, Room 118)

Session I: Moderator, Dave McNabb

8:00 a.m. Effects of slash density and treatment on shrub regeneration in small clearcuts. S. J. Hilton and D. A. Thornburg, Humboldt State University, Arcata, CA.

8:20 a.m. Tanoak root dieback: below- and above-ground site occupancy by stump-sprouts in SW Oregon. G.R. Ahrens and M. Newton, Oregon State University, Corvallis, OR.

8:40 a.m. Predicting the effects of tanoak competition on Douglas-fir growth. T. B. Harrington and J. C. Tappeiner, Oregon State University, Corvallis, OR.

9:00 a.m. Five-year effects of greenleaf manzanita and canyon live oak competition on Douglas-fir survival and growth. K. Baker-Katz, S. D. Tesch, and S. D. Hobbs. Forestry Intensified Research (FIR) Program, Dept. of Forest Science, Oregon State University, Corvallis, OR.

9:20 a.m. Protecting seedlings from burial on steep slopes in southwest Oregon. M. S. Crawford, D. H. McNabb. Forestry Intensified Research Program, Oregon State University, Corvallis, OR.

9:40 a.m. Morphology, root growth potential, and seedling development of Douglas-fir stocktypes. J. S. Graham and S. D. Hobbs, Department of Forest Science, Oregon State University, Corvallis, OR.

10:00 a.m. Coffee Break (one-half hour).

10:30 a.m. Root growth of white spruce seedlings during the first season after outplanting on mound, patch, and control site preparation treatments in the central interior of British Columbia. M. von der Gonna, and D. P. Lavendar. University of British Columbia, Vancouver, BC.

10:50 a.m. The impact of non-coniferous vegetation on the performance of Engelmann spruce (*Picea engelmannii* parry) seedlings on subalpine forest cutovers. C. L. Caza and J. P. Kimmins, University of British Columbia, Vancouver, BC.

11:10 a.m. Seedling survival, height growth, and variation in site factors after treatment of logging residues—a case study. W. Lopushinsky, USDA Forest Service, PNW Research Station, Wenatchee, WA.

11:30 a.m. Early survival and growth of wildling western hemlock planted beneath a thinned red alder stand. W. H. Emmingham, Oregon State University, Corvallis, OR.

11:50 a.m. LUNCH BREAK (until 1:00)

NOTE: There will be a Business Meeting Luncheon in the Rogue River Room of Stevenson Union at 12:00. Lunch price is included in your registration fee.

Forest Science (Science Building, Room 118)

Session II: Moderator, Don Hanley

1:00 p.m. Height variation of a 16-year-old Douglas-fir provenance/progeny trial. M. Kantarli, University of British Columbia, Vancouver, BC.

1:20 p.m. Comparative growth responses of Douglas-fir and grand fir at varying densities. E. C. Cole and M. Newton. Oregon State University, Corvallis, OR.

1:40 p.m. Juvenile height-growth of Pacific silver fir in western Washington. D. Coble, University of Washington, Seattle, WA.

2:00 p.m. Five-year results of cottonwood (*Populus trichocarpa,* Torr. & Gray) spacing trial in the Willamette Valley. K. J. Puettmann and W. H. Emmingham. Oregon State University, Corvallis, OR.

2:20 p.m. Wetwood and incipient decay in western hemlock. D. C. Shaw, K. W. Russell, W. R. Litkke, R. L. Edmonds, and C. H. Driver. University of Washington, Seattle, WA; State of Washington Dept. of Natural Resources, Olympia, WA; Weyerhaeuser Corp., Centralia, WA; and University of Washington, Seattle, WA.

2:40 p.m. Stem decay fungi associated with bird nesting cavities in western larch in northeast Oregon. Catherine A. Parks, Evelyn L. Bull, Gregory M. Filip, PNW Research Station, USDA Forest Service, LaGrande, OR; and Robert L. Gilbertson, University of Arizona, Tucson, AZ.

3:00 p.m. BREAK (one-half hour)

3:30 p.m. Relationships between understory vegetation and immature lodgepole pine site index in sub-boreal ecosystems of British Columbia. Q. L. Wang, University of British Columbia, Vancouver, BC.

3:50 p.m. Classification of red alder ecosystems in the Elk River tree farm. P. Bernardy, University of British Columbia, Vancouver, BC.

4:10 p.m. Engelmann spruce in western Washington. M. D. Murray, USDA Forest Service, Forestry Sciences Laboratory, Olympia, WA.

4:30 p.m. Managing for preservation and research at Mount St. Helens. P. M. Frenzen, USDA Forest Service, Amboy, WA.

Geology/Geography (Science Building, Room 108)

Session I: Moderator, Jad D'Allura

8:20 a.m. Effect of bedrock type on geochemistry and vegetation. Daniel B. Hawkins, University of Alaska, Fairbanks, AK. (Presented by Fred Lotspiech, Ph.D., Jacksonville, OR.)

8:40 a.m. Unique fossils and pseudofossils from Washington and British Columbia. W. R. Danner, University of British Columbia, Vancouver, BC.

9:00 a.m. Late-Pleistocene pluvial history of the Alvord Basin, Harney County, Oregon. D. N. Lindberg, Humboldt State University, Arcata, CA; and M. A. Hemphill-Haley, Woodward-Clyde Consultants, Oakland, CA.

9:20 a.m. Tectonic deformation of late Pleistocene shorelines in Warner Valley, Lake County, Oregon. Gilbert F. Craven, Department of Geology, Humboldt State University, Arcata, CA.

9:40 a.m. The petrology of the Summit Valley plutonic complex, Klamath Mountains, California. D. B. Parker, Humboldt State University, Arcata, CA.

10:00 a.m. BREAK (one-half hour)

10:30 a.m. A fifth Leavenworth substage in the Icicle-Chiwaukum Creeks area, north Cascade Range, Washington. W. A. Long, 123 Riverfront Dr., Cashmere, WA 98815.

10:50 a.m. Fumarole fields and thermal features at Mount Hood, Oregon. K. A. Cameron, U.S. Geological Survey, Cascades Volcano Observatory, Vancouver, WA.

11:10 a.m. An alluvial fan, a pediment, and tectonism of early Miocene Age, Sutton Mountain, Wheeler County, Oregon. I. R. Gordon and E. M. Taylor, Oregon State University, Corvallis, OR.

11:30 a.m. Development of a chronosequence of surfaces on an alluvial fan in the Owens Valley. J. F. Herrick, Humboldt State University, Arcata, CA.

11:50 a.m. LUNCH

Geology/Geography (Science Building, Room 108)

Session II: Moderator, Jad D'Allura

1:00 p.m. New data for large, late holocene debris flows in the Puyallup Basin, west of Mount Rainier, WA. P. T. Pringle, U.S. Geological Survey, Cascades Volcano Observatory, Vancouver, WA.

1:20 p.m. Analysis of kames composed of fine grained sediment, Waterville Plateau, Washington. B. A. May, P. K. Spencer, and R. J. Carson, Whitman College, Walla Walla, WA.

1:40 p.m. Geology of the northern portion of the likely fault lineament, Modoc County, northeastern California.

2:00 p.m. Early scientific expeditions on Mount Shasta. S. R. Mark, Ashland, OR.

2:20 p.m. Water resources planning in Oregon: a bold new direction. Claude W. Curran, Southern Oregon State College, Ashland, OR.

Zoology (Science Building, Room 275)

Session I: Moderator, John Sullivan

8:00 a.m. Foraging efficiency, rank order, and food spacing in social canines. John O. Sullivan, Southern Oregon State College, Ashland, OR.

8:20 a.m. Habitat quality as it relates to the territorial and mating system of the savannah sparrow. E. I. Rogers, Michigan State University, East Lansing, MI.

8:40 a.m. Habitat partitioning between sympatric coho salmon and dolly varden char juveniles. P. J. Mundy, USDA Forest Service, PNW Experiment Station, Corvallis, OR.

9:00 a.m. Adaptation of mountain beavers (*Aplodontia rufa*) to removal of underground nests. D. L. Campbell, J. D. Ocheltree, and M. G. Carey, USDA Animal & Plant Health Inspection Service, Animal Damage Control, Olympia, WA.

9:20 a.m. Reduction of small wild mammal population exposed to anticoagulant bait. M. G. Carey, USDA Animal & Plant Health Inspection Service, Animal Damage Control, Olympia, WA.

9:40 a.m. Diet and activity patterns of seepage-dwelling Coeur d'Alene Salamanders in northwestern Montana. A. G. Wilson, Jr., J. H. Larsen, Jr., and E. M. Simon, Washington State University, Pullman, WA.

10:00 a.m. BREAK (one-half hour)

10:30 a.m. Between-site variation in populations of the marine herbivore specialist *Placida Dendritica* (Mollusca: Gastropoda). C. D. Trowbridge, Oregon State University, Corvallis, OR.

10:50 a.m. cDNA cloning of *Fasciola Hepatica* mRNA. A. P. Taylor and D. R. Lightfoot, Eastern Washington University, Cheney, WA.

11:10 a.m. Production of monoclonal antibodies against *Cornebacterium diphtheria.* I. J. Beck and C. T. McNutt, Eastern Washington University, Cheney, WA.

11:30 a.m. Male chauvinism in foraging strategies of the sea otter, *Enhydra lutris.* Heather I. Sullivan, University of Washington, Seattle, WA; John W. Sullivan, Southern Oregon State College, Ashland, OR.

11:50 a.m. LUNCH

1:00 p.m. Physical, visual and temporal characteristics of perch selection and use by *Ceryle alcyon.* Matthew W. Snook and John O. Sullivan, Southern Oregon State College, Ashland, OR.

Science Education (Science Building, room 275)

Session I: Moderator, Don Mitchell

2:00 p.m. Bioaesthetics and integrated learning. F. D. Shepard, Southern Oregon State College, Ashland, OR.

2:20 p.m. A selective analysis of natural resource-based education: barriers, field projects, and curriculum models. L. K. Hilligoss, Siskiyou Environmental Education, Ashland, OR; and B. A. Middleton, Oregon State University, Corvallis, OR.

2:40 p.m. Integrated science concepts courses for pre-service elementary teachers of science. Don W. Mitchell, Southern Oregon State College, Ashland, OR.

Environmental Sciences (Science Building, room 171)

Session I: Moderator, Wayne Linn

1:00 p.m. Relationship of convection fog to vegetation of Redwood National Park, California. S. A. Harris, Humboldt State University, Arcata, CA.

1:20 p.m. Foliar penetration and volatilization of triclopyr butoxyethyl ester from deposits on leaves and glass slides. K. P. Bentson and L. A. Norris, Oregon State University, Corvallis, OR.

1:40 p.m. Spatial and temporal patterns of ozone in western Washington forests. F. A. Basabe and R. Edmonds, University of Washington, Seattle, WA.

2:00 p.m. Historical reconstruction of the amounts of large woody debris at northwest river mouths. P. A. Benner and J. R. Sedell, Oregon State University, Corvallis, OR; and USDA Forest Service, PNW Research Station, Forestry Sciences Lab, Corvallis, OR.

2:20 p.m. Estimating salmon production at a spawning channel on the Sacramento River. T. J. Hassler and S. A. Spaar, California Cooperative Fishery Unit, Humboldt State University, Arcata, CA.

CONTRIBUTED PAPER PRESENTATIONS
Friday, March 25, 1988

Forest Science (Science Building, Room 118)

Session III: Moderator, Bill Lopushinsky

8:00 a.m. The starch content of roots as an estimator of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) seedling quality. K. R. Forry and J. B. Zaerr, Oregon State University, Corvallis, OR.

8:20 a.m. Some observations on the phytosynthetic photon flux density under different cedar/hemlock stands with a note on *Gaultheria shallon* pursh vigor. C. Messier, K. J. Mackenzie, and J. P. Kimmins, University of British Columbia, Vancouver, BC.

8:40 a.m. Effects of photoperiod and plant growth regulatory substances upon the growth of coniferous seedlings. T. Kannangara, S. N. Silim, D. P. Lavendar, and L. Charleson, University of British Columbia, Vancouver, BC.

9:00 a.m. Effect of irrigation on growth and photosynthesis in alder and cottonwood plantations. R. A. Cellarius and D. S. DeBell, The Evergreen State College and USFS Forestry Sciences Laboratory, Olympia, WA.

9:20 a.m. Foliar moisture of Pacific Northwest subalpine conifers. J. K. Agee and M. H. Huff, National Park Service, University of Washington, Seattle, WA.

9:40 a.m. Thermal pumping in sap flow. O. E. Wagner, Wagner Research Laboratory, Rogue River, OR.

10:00 a.m. BREAK (one-half hour)

10:30 a.m. Ecophysiological responses of *Pseudotsuga menziesii* var. *glauca, Larix occidentalis, Pinus contorta* var. *latifolia,* and *Picea engelmannii* to planting on a mesic, south-exposed, burned and unburned site with two levels of vegetation removal. David Douglas-Crampton and D. P. Lavendar, University of British Columbia, Vancouver, BC.

10:50 a.m. Changes in Douglas-fir seedling growth as a result of soil source, organic matter content and seed source. D. S. Page-Dumroese and R. T. Graham, Intermountain Research Station, Moscow, ID.

11:10 a.m. Phosphorus fertilizer and growth of red alder seedlings in waterlogged soil. M. A. Radwan and D. S. DeBell, USDA Forest Service, Forestry Sciences Laboratory, Olympia, WA.

11:30 a.m. Soil microbiological properties following natural fire disturbance. S. L. Rose and A. S. Hutchins, Colorado State University, Fort Collins, CO; and USFS, Corvallis, OR.

11:50 a.m. LUNCH BREAK

Forest Science (Science Building, Room 118)

Session IV: Moderator, Lee Eddleman

1:20 p.m. The effects on vegetation of prescribed burning for wildlife habitat and range improvement in southeastern British Columbia. S. M. Thomson and M. C. Feller, University of British Columbia, Vancouver, B.C.

1:40 p.m. Influence of prescribed fire and cattle grazing on an elk winter range in Montana. C. Jourdonnais and D. Bedunah, School of Forestry, University of Montana, Missoula, MT.

2:00 p.m. Spring subalpine fire at Mount Rainier National Park: 1987 South Mowich fire. M. H. Huff, National Park Service Cooperative Park Studies Unit, College of Forest Resources, University of Washington, Seattle, WA.

2:20 p.m. Fertilization and liming of Douglas-fir and noble fir Christmas trees. Donald P. Hanley, Washington State University, Pullman, WA.

2:40 p.m. Laboratory investigations of moisture and mineral contributions to peat moss smoldering combustion limits. R. A. Hartford, Intermountain Research Station, Missoula, MT.

3:00 p.m. BREAK (one-half hour)

3:30 p.m. Measuring the heat evolved from smoldering dry peat moss in response to variable packing and mixing with inert powdered silica to mimic forest duff. W. H. Frandsen, Intermountain Research Station, Missoula, MT.

3:50 p.m. Precipitation throughfall, stemflow, and interception by western juniper canopies. L. E. Eddleman, Oregon State University, Corvallis, OR.

4:10 p.m. Nutrient dynamics of singleleaf pinyon needles. R. L. Everett and D. F. Thran, USFS Intermountain Research Station and University of Nevada, Reno, NV.

4:30 p.m. A forest plantation grazing study in the central Washington Cascade Range: musings of a scientist/herder. P. J. Edgerton, USDA Forest Service, Pacific Northwest Research Station, Wenatchee, WA.

Botany (Science Building, room 275)

Session I: Moderator, Darlene Southworth

8:00 a.m. Buried propagules in a temperate old-growth forest and their response to experimental disturbances. C. A. Ingersoll and M. V. Wilson, Oregon State University, Corvallis, OR.

8:20 a.m. Vegetation chronosequence along a sand deposition gradient at Dungeness Spit, Olympia Peninsula, Washington. T. N. Kaye, Oregon State University, Corvallis, OR.

8:40 a.m. Expectations vs. reality in early succession after debris torrents. J. L. Gecy and M. V. Wilson, Oregon State University, Corvallis, OR.

9:00 a.m. Understory recruitment of conifer seedlings on volcanic tephra. D. B. Zobel, Oregon State University, Corvallis, OR; and J. A. Antos, University of Victoria, Victoria, BC.

9:20 a.m. Growth and survival of experimentally transplanted populations of *Sidalcea nelsoniana,* a federal candidate species. R. J. Mishaga and J. L. Nicholls, CH2M HILL, Portland, OR; and McMinnville Water and Light Dept., McMinnville, OR.

9:40 a.m. Sprouting of pink heather in response to fire. L. L. Potash, University of Washington, Seattle, WA.

10:00 a.m. BREAK (one-half hour)

10:30 a.m. Mortality of ponderosa pine after low intensity prescribed fire at Crater Lake, Oregon. D. M. Swezy, University of Washington, Seattle, WA.

10:50 a.m. Autopolyploidy and tetrasomic inheritance in *Heuchera grossulariifolia.* P. G. Wolf, P. S. Soltis, and D. E. Soltis, Washington State University, Pullman, WA.

11:10 a.m. A question of identity and origin of a lamium hybrid new to Washington State. Ronald J. Taylor and Joseph Arnett, Western Washington University, Bellingham, WA.

11:30 a.m. The effect of the 85% methanol extract of *Alnus rubra* (red alder) on the survival and dietary utilization indices of *Malacosoma califronicum pluviale* (tent caterpillars). A. B. Adams, University of Washington, Seattle, WA.

11:50 a.m. LUNCH

Botany (Science Building, room 275)

Session II: Moderator, Frank Lang

1:20 p.m. A report on the ecology of the Olympic endemic, *Astragalus cottonii.* M. B. Gracz, University of Washington, Seattle, WA; T. N. Kaye, Dept. of Botany, Oregon State University, Corvallis, OR; and E. Schreiner, Olympic National Park, Port Angeles, WA.

1:40 p.m. Phytogeographic studies of Pacific coastal disjunct plants in the northern Rocky Mountains. C. C. Lorain and F. D. Johnson, University of Idaho, Moscow, ID.

2:00 p.m. Phenology of spring flowering plants in Eugene, Oregon. David H. Wagner, University of Oregon, Eugene, OR.

2:20 p.m. Sperm cells from flowering plants: structure and isolation. D. Southworth, Southern Oregon State College, Ashland, OR.

2:40 p.m. Phylogenetic implications of seed morphology in *Calochortus* (Liliaceae). B. D. Ness, Department of Botany, Washington State University, Pullman, WA.

3:00 p.m. BREAK (one-half hour)

1

EFFECTS OF SLASH DENSITY AND TREATMENT ON SHRUB REGENERATION IN SMALL CLEARCUTS. S.J. Hilton and D.A. Thornburg, Humboldt State Univ., Arcata CA.

Shrub response at the end of the first growing season was compared on plots representing four levels of slash density and treatment. The four treatment levels--burned slash, light slash, heavy slash and slash removed--were replicated on each of eight small clearcut units in a second growth redwood forest near Arcata. There was a significant difference between treatments in numbers of seedlings of blueblossom (Ceanothus thyrsiflorus Eschsch.)/m^2 and in numbers of plants of residual shrub species/m^2. Numbers of blueblossom seedlings were higher on burned plots than on light or heavy slash plots. Number of blueblossom seedlings/plot was a function of burn intensity and potential solar radiation. Number of blueblossom seedlings/plot on unburned plots was a function of potential solar radiation and percent of surface area with <25cm of litter. Burned plots are expected to have a heavy cover of blueblossom in 5-10 years. Unburned plots in warm areas may also have some blueblossom, but much less. Unburned plots may have more residual shrubs. This study was partially funded by the City of Arcata.

2

TANOAK ROOT DIEBACK: BELOW- AND ABOVE-GROUND SITE OCCUPANCY BY STUMP-SPROUTS IN SW OREGON. G. R. Ahrens and M. Newton. Oregon State University, Corvallis.

To evaluate stump-sprout maintenance of pre-harvest root systems, root and foliage biomass and surface area were estimated in mature tanoak stands and in adjacent sprout stands 2 to 8 years after cutting. Proportional to mature tanoak, rooting densities in 4-year-old sprout stands were 15, 48, 70, and 71 percent, in root diameter classes of <.25, .25-1, 1-2, and 2-5 mm, respectively. In mature forests, <1 mm roots comprised approximately 85 percent of total root surface area. Root/leaf weight ratios showed a trend of rapid recovery after crown removal. Carbohydrate reserve depletion and root/shoot adjustment are probable mechanisms resulting in net root dieback. Stump-sprouts do not maintain the extensive absorbing root system of the previous stand. Previous studies have shown higher carbon allocation, turnover rate and absorption activity for fine versus coarse roots. This explains the increase in root dieback with decreasing root size. Foliar control treatements at minimum tanoak root biomass (4-6 years) may be most effective for limiting competition in conifer plantations.

3

PREDICTING THE EFFECTS OF TANOAK COMPETITION ON DOUGLAS-FIR GROWTH. T.B. Harrington and J.C. Tappeiner, Oregon State Univ., Corvallis.

Data from a five-year-old study were used to develop equations for predicting Douglas-fir early growth losses from tanoak competition. Non-linear regression models were found to be most appropriate for predicting relative growth rates of individual Douglas-fir seedlings. Plot (0.04 ha) estimates of percent cover predicted Douglas-fir relative growth rate more accurately than tree-centered measures of the tanoak competition. Measurements of distance to surrounding tanoak did not improve the predictive ability of the tree-centered competition indices. Model simulations demonstrate the compounding effect of relative growth rate on the growth trajectories of Douglas-fir.

4

FIVE-YEAR EFFECTS OF GREENLEAF MANZANITA AND CANYON LIVE OAK COMPETITION ON DOUGLAS-FIR SURVIVAL AND GROWTH. K. Baker-Katz, S.D. Tesch and S.D. Hobbs. Forestry Intensified Research Program. Dept. of Forest Science, Oregon State Univ., Corvallis.

In 1983, Douglas-fir 1-0 container seedlings were planted on a steep, dry S.W. Oregon site among three levels of sprouting manzanita and canyon live oak, including: 1) 0.3 m tall sprouts killed with a herbicide one year before planting, 2) brush hand-slashed and removed just prior to planting, and 3) 0.5 m tall, 3-year-old sprouts. Fifth-year mean volume for seedlings currently growing in less than 20% cover (Trtmt 1) is 12 times that of those growing in 50% cover (Trtmt 2) and 36 times the volume of seedlings growing in greater than 70% cover (Trtmt 3). However, survival rates are generally high for all treatments and do not reflect the relative volume differences. The effects of increased levels of competition on seedling morphology were apparent by the second year and have increased through the fifth study year. Early plantation performance was reduced when vegetation management treatments left living roots that subsequently sprouted. Removing aboveground competition was not adequate to promote seedling growth.

5

PROTECTING SEEDLINGS FROM BURIAL ON STEEP SLOPES IN SOUTHWEST OREGON. M.S. Crawford, D.H. McNabb. Forestry Intensified Research Program. Oregon State University, Corvallis.

Ravel - rocks, soil, litter, and woody debris - may bury newly planted seedlings on steep slopes, increasing the risk of reforestation failure. The effects of ravel on seedlings protected by wood stakes and shingle-wedges placed upslope of 2-0 bareroot Douglas-fir seedlings were compared with unprotected seedlings on a recent unburned, clearcut in the western Siskiyou Mountains. The percentage of seedlings affected by ravel increased rapidly the first 8 months, then increased much slower before decreasing the third summer. The highest percentage of seedlings affected was 67, 40, and 21 for the unprotected and stake and shingle-wedge protected seedlings, respectively. Bent seedlings were the most common malady. After three growing seasons, survival was 82% for unprotected seedlings and 92.5% for those protected by stakes or shingle-wedges. Burial attributed to 58% of the mortality of unprotected trees and less than 2% of mortality in the stake and shingle-wedge treatments. As seedlings increase in size, their susceptibility to burial decreases.

6

MORPHOLOGY, ROOT GROWTH POTENTIAL, AND SEEDLING DEVELOPMENT OF DOUGLAS-FIR STOCKTYPES. J.S.Graham and S.D.Hobbs. Department of Forest Science, Oregon State University, Corvallis.

A study was conducted to compare the physiology and growth of different Douglas-fir stocktypes. Stocktypes were planted in simulated test plantations for two successive years. Seedling morphology and root growth potential were measured at planting time. Spring root dry weight increments, summer predawn water potentials and growth data were measured. Among stocktypes, root growth potential was unrelated to spring root development, summer water potential, or first season growth. It is concluded that initial dry weight or caliper are better predictors of performance than root growth potential for comparing stocktypes. Seedling survival was not significantly different among stocktypes.

7

ROOT GROWTH OF WHITE SPRUCE SEEDLINGS DURING THE FIRST SEASON AFTER OUTPLANTING ON MOUND, PATCH, AND CONTROL SITE PREPARATION TREATMENTS IN THE CENTRAL INTERIOR OF BRITISH COLUMBIA. M. von der Gonna and D. P. Lavendar. Univ. of British Columbia, Vancouver, British Columbia

White spruce seedlings were planted in three areas in the central interior of British Columbia after site preparation with machines which produced a mound or a patch. Root growth of the seedlings was measured at three intervals during the summer (45, 70 & 95 days after planting) and seedling biomass measurements and phosphorus and nitrogen content measured for seedlings harvested in the fall. Data collected thus far indicate that the mound site preparation technique permitted the greatest root growth, particularly on microsites which had high water tables. The site preparation techniques resulted in a range of above ground competition intensities for the seedlings but such competition was not reflected in the gross morphology of the seedling shoots. There are no correlations between the foliar nutrient content and the site preparation treatments.

8

THE IMPACT OF NON-CONIFEROUS VEGETATION ON THE PERFORMANCE OF ENGELMANN SPRUCE (PICEA ENGELMANNII PARRY) SEEDLINGS ON SUBALPINE FOREST CUTOVERS. C.L. Caza and J.P. Kimmins. Univ. of British Columbia, Vancouver, B.C.

Engelmann spruce seedlings were planted into two vegetation complexes on 4-yr-old cutovers in the subalpine forest of southern B.C. One complex was dominated by the ericaceous shrubs Menzeisia ferruginea and Rhododendron albiflorum, the other by the herbaceous perennial Valeriana sitchensis. Three treatments were applied within each complex: 1) removal of above-ground vegetation by clipping; 2) removal of all vegetation and forest floor by screefing; 3) no disturbance of vegetation. The objective was to assess spruce seedling performance, microclimatic variation and species responses to disturbance, between complexes. First season results indicated high soil moisture levels throughout the summer. Soil temperatures were lower and light levels greater under herbaceous species than shrubs. Seedling height growth and number of flushed buds were greater, and mechanical damage less within the shrub complex. Clipping resulted in regrowth of herbs within both complexes. There was little regrowth or invasion within screefed plots.

9

SEEDLING SURVIVAL, HEIGHT GROWTH AND VARIATION IN SITE FACTORS AFTER TREATMENT OF LOGGING RESIDUES--A CASE STUDY. W. Lopushinsky. USDA Forest Service, Pacific Northwest Research Station, Wenatchee, WA.

Survival, height growth, and nitrogen content of planted Douglas-fir and lodgepole pine seedlings, and variation in soil factors and air temperature were compared for 4 residue treatments. Residues were broadcast burned, piled and burned, totally removed, or left in place after clearcutting in a high elevation subalpine fir-lodgepole pine forest in north-central Washington. Poorest survival and height growth and greatest rodent damage to terminal shoots occurred where slash was left in place. Survival and growth generally were similar for the other treatments. There were no differences in soil nitrogen content related to residue treatment 1 year after slash treatment, but nitrogen concentration in new foliage the 2d year after planting was highest in the pile-and-burn treatment. Maximum air temperatures were recorded where residues were left in place. These findings emphasize the need for a better understanding of the interaction of residues and regeneration on these sites.

10

EARLY SURVIVAL AND GROWTH OF WILDLING WESTERN HEMLOCK PLANTED BENEATH A THINNED RED ALDER STAND. W.H. Emmingham. Oregon State University, Corvallis.

Wildling western hemlock seedlings were planted in early spring prior to mechanical and chemical thinning of a 13-year-old red alder stand. Survival of hemlock seedlings dropped from 78 to 52 percent between the end of the first and fifth growing seasons. During the 5th growing season growth of surviving seedlings in unthinned plots averaged only 9 cm. while those in thinned plots averaged about 45 cm. Direct shading by slash in the mechanical thinned plots contributed heavily to mortality in the first two years. In contrast, hemlock in the chemically thinned plots suffered damage from pinning as trees disintegrated from the top down. Clipping by ungelates and mountain beaver also contributed to mortality and growth losses. Establishment of a western hemlock stand beneath thinned alder stands appears feasible from a biological point of view. Overstory removal will be tested in the future.

11

HEIGHT VARIATION OF A 16 YEAR OLD DOUGLAS-FIR PROVENANCE/PROGENY TRIAL. M. Kantarli, Univ. of British Columbia, Vancouver, B.C., Canada.

Variation in the height growth was analysed after 16 years of growth. Results were compared with the 4th and 7th growing season measurements. The trial comprised 464 open pollinated families representing 58 provenances planted at U.B.C. Research Forest, Haney, B.C. in 1971. Significant variation was found between provenances and blocks. A strong genotype/environment interaction was detected at each of the three ages. Earlier analyses showed highly significant differences between families nested in each provenance, while this difference gradually diminished during the later years.

12

COMPARATIVE GROWTH RESPONSES OF DOUGLAS-FIR AND GRAND FIR AT VARYING DENSITIES. E.C. Cole and M. Newton. Oregon State Univ., Corvallis.

A series of Nelder (variable density) experiments were established to compare growth of Douglas-fir and grand fir in pure and mixed stands. Eight-year results indicate mixtures of the two species did not increase standing biomass/hectare. In mixed stands, average grand fir volume ranged from 3500 to 20000 cm^3/tree, and Douglas-fir volume from 5500 to 27000 cm^3/tree. In pure stands, average volumes ranged from 2000 to 15000 cm^3/tree for grand fir and 4000 to 24000 cm^3/tree for Douglas-fir. Douglas-fir trees were significantly taller and height growth significantly greater than grand fir at most densities. Basal diameters were similar at low densities, but Douglas-fir trees were larger at high densities. Height to diameter ratios were generally higher for Douglas-fir than grand fir, regardless of density. Ratios for both species increased with increasing density. Animal damage, primarily rodent girdling and deer or elk racking, was more prevalent on grand fir.

13

JUVENILE HEIGHT-GROWTH OF PACIFIC SILVER FIR IN WESTERN WASHINGTON. D. Coble. Univ. of Washington, Seattle.

Height-growth of young (20-30 yrs.) Pacific silver fir (Abies amabilis [Dougl.] Forbes) trees was examined using stem analysis data. The data were compared to height-growth predicted by existing Pacific silver fir height-age curves. Actual height-growth was found to follow predicted height-growth; however, young Pacific silver fir trees exhibit erratic early height-growth. Understanding height-growth of Pacific silver fir over a range of age classes is valuable in managing upper-slope forests.

14

5-YEAR RESULTS OF A COTTONWOOD (POPULUS TRICHOCARPA, TORR. & GRAY) SPACING TRIAL IN THE WILLAMETTE VALLEY. K.J.Puettmann and W.H. Emmingham. Oregon State University, Corvallis.

A spacing trial was conducted to investigate the feasibility of using black cottonwood as a crop in flood plane areas. Cottonwood slips were planted at four different spacings on a river bottom site near Corvallis. All plots were treated with Roundup to remove competing vegetation within 5 feet of each tree. In part of the very narrow spacing plots a row thinning increased the spacing from 4'x5' to 8'x5' after the second growing season. After 5 years the average diameter, height and stem volume increment in the narrow spacings (4'x5', 6'x6', 8'x5') was significantly greater than in the wide spacings (12'x12', 20'x20'). There was no significant difference within the two groups. We hypothesize that the unexpected result (i.e., better growth on less growing space) was due to more complete control of the competing plant community on the narrow spacing plots.

15

WETWOOD AND INCIPIENT DECAY IN WESTERN HEMLOCK. D.C. Shaw, K.W. Russell, W.R. Litkke, R.L. Edmonds, and C.H. Driver Univ. of Washington, Seattle, State of Washington, Dept. of Natural Resources, Olympia, Weyerhauser Corp., Centralia, Washington, and Univ. of Washington.

Wetwood and incipient decay are two distinct types of discolored wood in living trees. Wetwood is any watersoaked appearance in nonliving wood of live trees, whereas incipient decay is discolored wood caused by the initial enzymatic breakdown. In western hemlock, wetwood appears to be a part of normal tree development and forms in compartmentalized columns associated with root and branch death, and wounding. Wetwood begins as light brown zones, eventually becoming pinkish-red. Decay fungi are usually not present in wetwood. Incipient decay caused by Heterobasidion annosum (Fr.) Bref. and Armillaria sp. is dark brown and is associated with the leading margin around advanced decay. It is usually surrounded by wetwood, and is restricted to the wetwood column.

16

STEM DECAY FUNGI ASSOCIATED WITH BIRD NESTING CAVITIES IN WESTERN LARCH IN NORTHEAST OREGON. Catherine A. Parks, Evelyn L. Bull, Gregory M. Filip. Pacific Northwest Research Station, USDA Forest Service, LaGrande, Oregon, and Robert L. Gilbertson, Univ. of Arizona, Tuscon.

Although snags (standing dead trees) are the most common nest sites for cavity nesting birds and animals, live trees may also accomodate them. We sampled 18 live western larch (Larix occidentalis Nutt.) containing cavities, for incidence of decay. All cavities were associated with decay fungi. Identification of these fungi may lead to live-tree inoculation trials and potentially--wildlife trees.

17

RELATIONSHIPS BETWEEN UNDERSTORY VEGETATION AND IMMATURE LODGEPOLE PINE SITE INDEX IN SUB-BOREAL ECOSYSTEMS OF BRITISH COLUMBIA. Q.L. Wang, Univ. of British Columbia, Vancouver, B.C., Canada.

To determine the usefulness of understory vegetation in immature lodgepole pine ecosystems in the Sub-boreal Spruce biogeoclimatic zone in differentiating biologically-equivalent sites, the vegetation of fifty-four ecosystems representing contrasting climates and soil moisture regimes was sampled and analyzed. Regression analysis showed that there is a good relationship between lodgepole pine site index and vegetation units (R^2 = 0.75). These results suggest that understory vegetation of immature lodgepole pine ecosystems is a useful indicator of site quality and can be used for identification of site associations and, if desired, to estimate lodgepole pine site index.

18

CLASSIFICATION OF RED ALDER ECOSYSTEMS IN THE ELK RIVER TREE FARM. P. Bernardy. Univ. of British Columbia, Vancouver, B.C.

The vegetation and soils of red alder-dominated ecosystems in the Elk River Tree Farm, near Campbell River, B.C., were sampled and analyzed, and the ecosystems classified into a hierarchy of vegetation and site units, using the methods and system of biogeoclimatic classification. Identification and interpretive keys were developed to provide assistance to the B.C. Forest Products foresters in selecting the most suitable conifers for rehabilitating hardwood ecosystems on a site-specific basis.

19

ENGELMANN SPRUCE IN WESTERN WASHINGTON M. D. Murray. USDA Forest Service, Forestry Sciences Laboratory, Olympia, Washington.

Engelmann spruce (Picea engelmannii) has its major distribution in the Rocky Mountains, one of the highest and coldest forest environments in the western United States. It also grows on the summit and eastern slopes of the Cascade Range in Washington and Oregon and at limited locations west of the Cascades in Washington. Five locations of P. engelmannii in western Washington were examined. Two locations have a regional maritime climate; three others are in rain shadow areas and have some characteristics of a continental climate. Spruce at all locations attained large size. One tree was over 8 feet in diameter and 238 feet tall. Vigorous spruce regeneration was found in a clearcut at one location. This conifer may be worth managing in certain habitats in western Washington.

20

MANAGING FOR PRESERVATION AND RESEARCH AT MOUNT ST. HELENS. P. M. Frenzen, USDA Forest Service, Amboy, Washington.

The Mount St. Helens National Volcanic Monument (NVM) is dedicated to the preservation of natural processes and features created by the 1980 eruptions. Visitor appreciation of preservation objectives is enhanced through participation in environmental education and interpretative programs. The principal challenge facing NVM managers is to provide for visitor access and enjoyment while ensuring that natural processes procede substantially unimpeded. To accomplish this the NVM is developing a baseline monitoring program. Information derived from research conducted in the NVM is recognized as an important part of this effort. Scientists interested in research opportunities are encouraged to contact the Monument Scientist to explore ideas for research initiatives that build upon baselines established since 1980. A symposium will be held on June 11 and 12, 1988 to discuss opportunities for research in the NVM.

21

THE STARCH CONTENT OF ROOTS AS AN ESTIMATOR OF DOUGLAS-FIR [Pseudotsuga menziessii (Mirb.) Franco] SEEDLING QUALITY. K.R. Forry and J.B. Zaerr. Oregon State Univ., Corvallis.

A range of quality was created among the seedlings by lifting at different times and applying a series of freezing, drying, or cold storage treatments. Seedling quality was defined as the ability of a seedling to grow on a designated planting site. The starch content of roots (percent dry weight) was determined enzymatically. Starch content varied considerably from year to year and increased from about 2% in October to almost 11% by March. Starch content decreased rapidly during periods of cold storage and some seedlings completely utilize their reserves within two months of storage, but still fare quite well in the field. The starch content of roots, by itself, was unreliable as an estimator of Douglas-fir seedling quality, but may prove useful in conjunction with other quality assessment methods. This research was supported in part by the USDI BLM and USDA FS FIR program grant #0376 and the D.L. Phipps State Forest Nursery.

22

SOME OBSERVATIONS ON THE PHOTOSYNTHETIC PHOTON FLUX DENSITY UNDER DIFFERENT CEDAR/HEMLOCK STANDS WITH A NOTE ON GAULTHERIA SHALLON PURSH VIGOR. C. Messier, K.J. Mackenzie, and J.P. Kimmins. Univ. of British Columbia, Vancouver, Canada.

Measurements of photosynthetic photon flux density (PPFD: 400-700 nm) were made under both clear and overcast sky conditions above and at various levels within four western redcedar/western hemlock stands. These stands were chosen to cover a wide range of understory cover of Gaultheria shallon. As expected, the PPFD and the understory cover of Gaultheria shallon decreased with an increase in crown cover. The absolute PPFD was higher under overcast sky conditions for two stands. Under clear sky conditions sunflecks accounted for more than 45% of the PPFD for all stands. Gaultheria shallon was not found growing below 25 u mol s^{-1} m^{-2} (5% of the PPFD measured above the stands under overcast sky conditions).

23

EFFECTS OF PHOTOPERIOD AND PLANT GROWTH REGULATORY SUBSTANCES UPON THE GROWTH OF CONIFEROUS SEEDLINGS. T. Kannangara, S. N. Silim, D. P. Lavendar, and L. Charleson. Univ. of British Columbia, Vancouver, British Columbia, Canada

Seedlings of five British Columbia conifer species were treated with long and short photoperiods and with applications of plant growth regulators during one month in late summer of their first growing season. Endogenous abscisic acid (ABA) levels of seedlings given the photo period treatments were analyzed after purification of extracts by immunoaffinity column chromatography. Immunoaffinity columns were prepared by linking monoclonal antibodies generated against ABA to sepharose beads. Data which describe levels of ABA after the photoperiod treatments will be related to subsequent growth and phenology of the seedlings. Both growth regulator levels and seedling growth response varied with treatment and species.

24

EFFECT OF IRRIGATION ON GROWTH AND PHOTOSYNTHESIS IN ALDER AND COTTONWOOD PLANTATIONS. R.A. Cellarius and D.S. DeBell, The Evergreen State Col. and USFS Forestry Sciences Lab., Olympia, WA.

To determine optimum conditions for growth in field situations, plantations of red alder and cottonwood were established with a variety of treatments. Growth, photosynthesis, and stomatal behavior measurements have been made in irrigated (+Ir) and nonirrigated (-Ir) 2-year old stands. These studies show that in mid August, photosynthesis (PS) is much lower in -Ir alder, especially at times of high water stress, due primarily to decreased stomatal conductance (SC):

Time	PS(-Ir/+Ir)	SC(-Ir/+Ir)
10 AM	30-50%	10-20%
3 PM	0- 5%	4- 6%

Total growth of -Ir alder is only 60% that of +Ir stands, as measured by height and stem diameter, and the -Ir trees are visibly less vigorous. Preliminary data suggest there is a smaller difference between -Ir and +Ir cottonwood (-Ir/+Ir ratios of 75% for PS, 50-90% for SC, and 85% for total growth).

25

FOLIAR MOISTURE OF PACIFIC NORTHWEST SUBALPINE CONIFERS. J.K. Agee and M.H. Huff. National Park Service/University of Washington, Seattle.

Live foliar moisture was measured for subalpine fir and red fir in Washington and Oregon. New foliage had higher moisture content than older foliage or small twigs. New foliage moisture content declines over the season from early season values of 300+ percent to late season values of 100+ percent. Minimum values found were higher than in many other areas, but are low enough to encourage crown ignition under severe fire weather in mid- to late summer.

26

THERMAL PUMPING IN SAP FLOW. O.E. Wagner. Wagner Research Lab., Rogue River, OR.

Experiments indicate that the present theory of tree sap flow is inadequate and that at least some pumping is involved: 1. Tobiessen et. al. 2. Wagner: (a) Salt left in xylem samples tends to move toward one end. (b) Fresh wood samples were forced to pump water with the proper application of electric fields. (c) Potential differences from wood samples (and trees) indicate a distinct anisotropy. (d) A pressure change on salt filled wood samples produces a predictable (from the samples original tree orientation) change in output voltage. (e) Application of ac voltages to trees and samples produce a resultant output dc voltage related to the xylem orientation in the tree. (f) An anisotropy ratio, that is an indicator of a tree's potential height, is measureable.

1.P. Tobiessen et. al.: Plant Physiol. 48, 303-304(1971)
2.O.E. Wagner: Bull. Amer. Phys. Soc. 33(1), 65(1988)

27

ECOPHYSIOLOGICAL RESPONSES OF PSEUDOTSUGA MENZIESII VAR. GLAUCA, LARIX OCCIDENTALIS, PINUS CONTORTA VAR. LATIFOLIA, AND PICEA ENGELMANII TO PLANTING ON A MESIC, SOUTH-EXPOSED, BURNED AND UNBURNED SITE WITH TWO LEVELS OF VEGETATION REMOVAL. David Douglas-Crampton & D. P. Lavendar. Univ. British Columbia, Vancouver, B.C.

Seedlings were planted in the spring of 1986 on a prescribed burn of three intensities and in an unburned control. In 80 of the 160 plots, competing vegetation was removed entirely for both growing seasons. Transpiration rates and stem moisture potentials of the four species of seedlings studied reflected a non-limiting soil moisture potential throughout the two growing seasons. Significant differences in relative growth between species and between the burned and unburned sites suggest that the varying stomatal apertures found during midday sampling and the different dates of bud-set were diverse enough to effect the overall growth. Height growth and total biomass production was observed to be greatest in Larix occidentalis, then Pinus contorta var. latifolia, then Picea engelmanii, and least in Pseudotsuga menziesii var. glauca.

28

CHANGES IN DOUGLAS-FIR SEEDLING GROWTH AS A RESULT OF SOIL SOURCE, ORGANIC MATTER CONTENT AND SEED SOURCE. D.S. Page-Dumroese and R.T. Graham. Int. Res. Sta., Moscow, ID.

Interactions between soil organic matter, source and seed source of Douglas-fir were evaluated. Physical characteristics of the seedlings were measured after planting in two soil sources (local and non-local) from Northern Idaho. Three organic matter percentages were used. Seed was also taken from two sources, soil and seed were interchanged. Treatments consisted of moisture stress, nutrient stress, elimination of mycorrhizal fungi and no external stress. Seedlings grown in "home" soil in a mix of organic and mineral soil performed best. Harvest techniques should emphasize maintainance of organic matter levels.

29

PHOSPHORUS FERTILIZER AND GROWTH OF RED ALDER SEEDLINGS IN WATERLOGGED SOIL. M. A. Radwan and D. S. DeBell. USDA Forest Service, Forestry Sciences Laboratory, Olympia, Washington.

A 1-year lathhouse test was conducted to compare performance of potted red alder seedlings grown in 2 different soils, under 2 different soil-water conditions (drained and waterlogged), with and without phosphorus (P) fertilizer. The soils, S-I and S-II, were collected, respectively, from wet and well-drained areas of one young alder plantation in western Washington. Triple superphosphate was applied at 0, 200, and 500 kg P/ha. Growth was affected by all factors studied and their interactions. Shoot and root growth were mostly greater in S-II than in S-I. Without P, waterlogging reduced root and shoot growth in both soils. Application of P fertilizer enhanced shoot and root growth in drained S-I but not in drained S-II; it improved growth of waterlogged seedlings in both soils. Phosphorus fertilization, therefore, shows promise for increasing alder productivity in the Pacific Northwest, especially on poorly drained sites, which are inherently better suited for alder than for most conifers.

30

SOIL MICROBIOLOGICAL PROPERTIES FOLLOWING NATURAL FIRE DISTURBANCE S.L. Rose and A.S. Hutchins, Colorado State Univ., Fort Collins, Co; and USFS, Corvallis, Or.

Soil samples were collected from burned and unburned forests at the Tumalo Falls watershed, Bend, Oregon, in 1979 immediately after an intense fire. We sampled again in 1980 and 1981 in an effort to monitor the impact of fire on soil chemical and microbiological properties. Organic matter, calcium, and bacterial and fungal populations declined after the fire, while NO_3 and NH_4 and actinomycetes increased in burned soil. However, we found decreased populations of streptomyces antagonistic to the fungal pathogen Fomes annosus in all burned soils. All microbial populations in both soils increased after 1 yr, perhaps reflecting temperature and moisture patterns rather than fire effects. N-mineralization was highest in post-burn soils and followed population dynamics. In addition, the presence of mycorrhizal fungal propagules, as measured by a greenhouse bioassay, decreased significantly in burned soils and no increase was evident during the 3 yrs of the study. We propose to resample the sites in 1989 to monitor soil properties 10 years after fire disturbance.

31

THE EFFECTS ON VEGETATION OF PRESCRIBED BURNING FOR WILDLIFE HABITAT AND RANGE IMPROVEMENT IN SOUTHEASTERN BRITISH COLUMBIA. S.M. Thomson and M.C. Feller. University of British Columbia, Vancouver, B.C.

The ecological effects of prescribed burning for wildlife habitat and range improvement was studied on a shrub/grassland plant community in the southern Rocky Mountain Trench. An extensive inventory of previous operationally burned areas was conducted. Plots were established to compare the effects of experimental spring and fall burning on the percent cover and current annual growth of seven key browse and forage species. The results for the first growing season following burning indicate that there is significantly less percent cover and current annual growth of bitterbrush (Purshia tridentata) on fall burned plots compared with unburned plots. There was no significant difference between fall burned plots and unburned plots for all other key species. The results for the operationally burned areas support these data in most cases, although effects are variable. Regression equations relating current annual growth and total shrub biomass to crown dimensions were developed for bitterbrush.

32

INFLUENCE OF PRESCRIBED FIRE AND CATTLE GRAZING ON AN ELK WINTER RANGE IN MONTANA. C. Jourdonnais and D. Bedunah. School of Forestry, Univ. of Montana, Missoula.

In 1983 we began a study on the Sun River Wildlife Management Area to examine the impact of prescribed fire and cattle grazing on botanical standing crop of a rough fescue (Festuca scabrella) community. Our study area had received little use by elk (Cervus elaphus) which had allowed plant litter to accumulate (become wolfy); thereby, decreasing the community's attractiveness to foraging elk. Our study objective was to develop techniques to remove excess plant litter and increase forage availability and quality for elk wintering on the management area. Our treatments were backing-fires and head-fires during the fall of 1983 and spring of 1984, grazing by 104 cow/calf pairs in the fall of 1983, and a control. Burn and cattle grazing treatments reduced total standing crop and rough fescue standing crop in the initial growing season following treatments but not in the second and third post-treatment growing seasons. Utilization of the area by elk increased dramatically and maybe resulting in a downward trend in rough fescue production.

33

SPRING SUBALPINE FIRE AT MOUNT RAINIER NATIONAL PARK: 1987 SOUTH MOWICH FIRE. M.H. Huff. National Park Service Cooperative Park Studies Unit, College of Forest Resources, AR-10, University of Washington, Seattle, WA 98195.

One 2500 sq m permanent plot was established on the north slope of the May 7, 1987 Mowich Fire to 1) document the ecological effects of a crown fire burning over a snow-covered understory and 2) establish a research site to monitor the long-term ecological effects of the fire. Most of the burning took place in the foliage of tall and large 400-600 year old mountain hemlocks. Pacific silver fir was generally only singed by the blaze. Tree survival was nearly 60 percent for trees taller than 5 m, however most survivors had more than 50 percent of their crown damaged and additional mortality is expected. Most of the trees less than 2 m tall, primarily Pacific silver fir, were buried under snow at the time of the fire. These survivors are expected to dominate future stand development.

34

FERTILIZATION AND LIMING OF DOUGLAS-FIR AND NOBLE FIR CHRISTMAS TREES. Donald P. Hanley, Washington State University, Pullman, WA.

Douglas-fir and noble fir Christmas trees in Western Washington were treated with fertilizer and lime in order to study the impacts of the treatments and their interactions on tree vigor and current season needle mass. A randomized complete block design was used with 4 locations, 6 fertilizer/ lime treatments, and 3 replications at each location for both Douglas-fir and Noble fir. Treatments included lime, 21-0-0, and 10-20-20, each at two application rates. Study statistics that could be observed by growers were selected and included tree height increment, as an indicator of tree vigor, and current season needle weight, as an indicator of tree fullness. Results to date indicate an overall weak statistical significance to the fertilizer/ lime treatments, a strong significance to individual locations, and a weak association between lime and needle weight. Third-year study measurements will be made in 1988, with final recommendations available in the fall of 1988.

35

LABORATORY INVESTIGATIONS OF MOISTURE AND MINERAL CONTRIBUTIONS TO PEAT MOSS SMOLDERING COMBUSTION LIMITS. R.A.Hartford. Intermountain Research Station, Missoula, Montana.

Predictions of duff reduction and percent mineral soil exposure are based primarily on the moisture content of the duff. Smoldering combustion in duff is also affected by incorporated mineral soil. Fuel beds composed of moisture-conditioned peat moss and mineral soil simulate duff. Smoldering limits in peat moss, as they are influenced by moisture, mineral soil content, and the type of mineral soil, have been identified through laboratory burns testing for sustained combustion. Logistic regression analysis was applied to the burn/no-burn data to develop classification equations for the prediction of sustained combustion.

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MEASURING THE HEAT EVOLVED FROM SMOLDERING DRY PEAT MOSS IN RESPONSE TO VARIABLE PACKING AND MIXING WITH INERT POWDERED SILICA TO MIMIC FOREST DUFF. W.H.Frandsen Intermountain Research Station, Missoula, Montana.

Fuel arrays are constructed by packing a mixture of peat moss and powdered silica to mimic forest duff. Organic concentrations were chosen to represent natural conditions that range from .09 to .18 grams per total bulk volume (cm^3). Powdered silica was added to obtain mixtures of one to four times the amount of smoldering organic mass. Greater concentrations eliminate smoldering. The heat evolved in response to these concentrations is obtained by monitoring the oxygen consumed by the fuel array which is directly correlated to the heat generated during combustion. Heats evolved from smoldering are related to the organic and inorganic (inert) concentrations in the fuel array.

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PRECIPITATION THROUGHFALL, STEMFLOW AND INTERCEPTION BY WESTERN JUNIPER CANOPIES. L.E. Eddleman. Oregon State Univ.

Precipitation throughfall and stemflow were measured for 24 storm events on 12 Juniperus occidentalis trees of variable size. Canopy interception was determined by difference: total precipitation minus throughfall and stemflow. Stemflow accounted for less than 3 percent of the precipitation and declined as trees increased in size. Interception was greater than 50 percent and reached 68 percent in the largest size class. Interception was positively correlated with precipitation amount, due in part to larger storms coming as snow which did not penetrate the canopy.

38

NUTRIENT DYNAMICS OF SINGLELEAF PINYON NEEDLES. R. L. Everett and D. F. Thran. USFS, Inter.Res.Sta. and Univ. of Nev., Reno.

This study defined the annual nutrient demands created by new foliage on branches of singleleaf pinyon (Pinus monophylla Torr. & Frem.) and estimated the proportion of that demand met by translocation from needles on the same branch. Translocation from one to 12 year old live and abscissing needles could provide 20% of the N and 50% of the P required by the annual 20% increase in new needles on the branch. Needles were a nutrient sink for Ca, Mg, Fe, Zn, and Mn for the life of the needle. Needles were first nutrient sinks then sources for N, K, and Cu. Extensive stem branching creates a new needle nutrient demand that can not be met by translocation from existing needles or their abscission. A majority of N, P, Ca, Mg, Fe, Zn, and Mn must be translocated from other parts of the tree and ultimately the soil to meet annual foliage demands. Zones of nutrient enrichment in organic and mineral soil under the tree crown are considered likely sources for meeting nutrient demands not met by translocation.

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FORAGING EFFICIENCY, RANK ORDER AND FOOD SPACING IN SOCIAL CANINES

John O. Sullivan

Social canines, Australian part-dingo stock dogs, were presented food in clumped and spaced patterns. Rank order in seperate male and female dominance hierarchies was determined. Determination of the impact of rank position on success in obtaining food under two different spacial patterns (clumped vs. spaced) was determined.

40

HABITAT QUALITY AS IT RELATES TO THE TERRITORIAL AND MATING SYSTEM OF THE SAVANNAH SPARROW. E.I. Rogers. Michigan State Univ., East Lansing, Michigan.

An individually marked breeding population of savannah sparrows, Passerculus sandwichensis, was observed for four years, from 1984-1987, in southern Michigan. Male and female territorial behaviors were recorded. Locations and areas of territories were mapped and measured. Nest success was documented and nest spacing was measured. Incidences of polygyny were documented at 5-25% levels. In 1987, habitat quality was quantified by estimating available foraging space per territory. Territory size in both males and females is inversely related to the density of foraging space on the territory. Furthermore, females appear to settle in greater densities in areas with high concentrations of foraging space. These differing settling densities may in some cases contribute to the incidence of polygyny in this species.

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HABITAT PARTITIONING BETWEEN SYMPATRIC COHO SALMON AND DOLLY VARDEN CHAR JUVENILES. P.J. Mundy. U.S.D.A. Forest Service, Pacific Northwest Experiment Station, Corvallis, Oregon.

Juvenile coho salmon (Oncorhynchus kisutch) and Dolly Varden char (Salvelinus malma) from sympatric Alaskan populations were observed in an artificial stream to determine the possible mechanism of habitat partitioning between the two species. Observations were made with the species alone and together. When the species were observed together salmon occupied positions higher in the water column and further from protective cover than Dolly Varden. These patterns were maintained when species were observed alone. It is therefore suggested that selective segregation is the mechanism by which these species partition habitat.

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ADAPTATION OF MOUNTAIN BEAVERS (Aplodontia rufa) TO REMOVAL OF UNDERGROUND NESTS. D.L. Campbell, J.D. Ocheltree, and M.G. Carey. USDA, Animal & Plant Health Inspection Service, Animal Damage Control, Olympia, WA.

Mountain beavers typically invade and occupy existing burrow systems after the residents have been removed to control damage to Douglas-fir plantations. These animals continue to cause tree damage. In this study, radio telemetry was used to evaluate nest removal for reducing reinvasion. Radio-collars were used to monitor individual animals; special pencil-type transmitters tied to nest materials helped locate nests and food caches. Paired treatments in a plantation and adjacent timber included removal of nests but not animals, removal of nests and animals, removal only of animals, and no removal of either nests or animals (controls). Mountain beavers soon took over vacated nests or used their own nearby food caches as new nests. Only one mountain beaver died from exposure after its nest was removed. The removal of nests by hand or with explosives does not appear to be a practical method to prevent reinvasion by mountain beavers in these habitats.

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REDUCTION OF A SMALL WILD MAMMAL POPULATION EXPOSED TO ANTICOAGULANT BAIT. M.G. Carey. USDA, Animal & Plant Health Inspection Service, Animal Damage Control, Olympia, WA.

Small mammal populations were censused by live trapping, tagging, and subsequent recapturing in two separate 1-acre wooded enclosures in conjunction with tests evaluating an anticoagulant bait containing 0.0052% diphacinone for control of mountain beavers (Aplodontia rufa). The treatment population of deer mice (Peromyscus maniculatus) decreased 83% (from 18 to 3) immediately after baiting and was still down about 44% (from 18 to 10) 6 weeks later. Voles (Microtus sp. and Clethrionomys gapperi) decreased from 4 to 0 individuals; there were only 2 individuals 6 weeks later. No previously marked animals were recaptured in the treated area after baiting with diphacinone. The control population of deer mice exposed to food pellets as bait increased from 9 to 15; 5 previously marked animals were recaptured after treatment. Voles increased from 3 to 9. Other studies indicate that secondary poisoning may be associated with the use of this 0.0052% diphacinone bait for mountain beavers if poisoned small mammals are eaten by certain avian predators.

44

DIET AND ACTIVITY PATTERNS OF SEEPAGE-DWELLING COEUR D'ALENE SALAMANDERS IN NORTHWESTERN MONTANA. A.G. Wilson, Jr., J.H. Larsen, Jr., and E.M. Simon. Washington State Univ., Pullman.

Periodic censusing of a population of seepage-dwelling Plethodon vandykei idahoensis (Coeur d'Alene salamander) provided information on environmental factors that influence surface activity, and stomach flushing permitted analysis of the diet. Activity was almost entirely nocturnal and had a weak, positive correlation with nighttime substrate temperature. During June, July, and August only, activity was periodically reduced and had a strong, negative correlation with the number of days since the last rain. Plethodon v. idahoensis enters standing water and hydropetric areas and this is reflected in the presence of aquatic insects in its diet. This salamander commonly exploits very wet microhabitat, such as seepages, where it is insulated from climatic extremes. Conditions in seepages that are favorable to P. v. idahoensis center around local bedrock fracturing that results in the emergence of water at constant temperature and provides daytime and seasonal shelter.

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BETWEEN-SITE VARIATION IN POPULATIONS OF THE MARINE HERBIVORE SPECIALIST PLACIDA DENDRITICA (MOLLUSCA: GASTROPODA). C.D. Trowbridge. Oregon State Univ., Corvallis.

The ascoglossan opisthobranch Placida dendritica is a stenophagous marine herbivore, specializing on the low intertidal green algae Codium and Bryopsis. Placida appears on the algae in April and persists until September or October along the central coast of Oregon. The species is an annual to subannual, with several overlapping generations each season. The ascoglossan is abundant at some sites but not at others. Placida is less abundant at sites where heavy sand scour and burial occur than at adjacent areas with low sand impact. Results from laboratory feeding experiments indicate that Placida prefers algae from sites with low ascoglossan abundances, regardless of sand influence.

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cDNA CLONING OF FASCIOLA HEPATICA mRNA. A.P.Taylor and D.R.Lightfoot, Eastern Washington University, Cheney.

To prepare a recombinant DNA derived vaccine containing the antigens of liver fluke (Fasciola hepatica), it was necessary to construct an expressing copy DNA library of the parasite's mRNA. The cloning strategy was designed to minimize the number of procedural steps needed and to optimize the synthesis of full length DNA copies of the mRNAs. An expressing plasmid, pKK223-3, was the vector locus for polyA mRNA association, cDNA synthesis, and recircularization. The technique includes triple homopolymeric tailing of the vector and the use of dideoxy nucleotides.

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BURIED PROPAGULES IN A TEMPERATE OLD-GROWTH FOREST AND THEIR RESPONSE TO EXPERIMENTAL DISTURBANCES. C.A. Ingersoll and M.V. Wilson. Oregon State University, Corvallis.

On-site survivors, in the form of buried seeds and vegetative parts, are a primary source of propagules contributing to regeneration of vegetation following disturbance. Propagule bank composition and response to experimental disturbance (canopy removal, burning, and churning of soil) was studied at one site in the western Cascade Mountains of Oregon. Results showed that the majority of individuals (74%) emerged from vegetative parts, and that the buried seed bank was depauperate in comparison even with many other coniferous forests. Disturbance significantly reduced vegetative regeneration, but had no effect on emergence of seedlings. Species response to disturbance was highly individualistic. These results provide experimental evidence supporting models of succession incorporating both deterministic and stochastic factors in alternative successional pathways.

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VEGETATION CHRONOSEQUENCE ALONG A SAND DEPOSITION GRADIENT AT DUNGENESS SPIT, OLYMPIC PENINSULA, WASHINGTON. T. N. Kaye. Oregon State Univ., Corvallis.

Maps and aerial photographs indicate that sand accretion has rapidly extended the beach at Dungeness Spit, Washington since 1915. The Dungeness flora is relatively pristine, with an abundance of native species. Sixty-one 4 x 4 m plots were sampled along a 244 m transect parallel to a substrate age gradient to describe successional trends in the vegetation. Vegetation patterns shown by detrended correspondence analysis ordination are significantly correlated with distance from the spit terminus, and therefore with substrate age. Species diversity [exp(H')] increased significantly with substrate age, while abundance of heavy driftwood decreased significantly with substrate age. Species distributions indicated an increase in substrate stability with time. Species tolerant of sand burial and erosion were common on recent substrates, while species intolerant of sand movement were more abundant in older areas.

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EXPECTATIONS VS. REALITY IN EARLY SUCCESSION AFTER DEBRIS TORRENTS. J.L. Gecy and M.V. Wilson. Oregon State University, Corvallis.

An experimental debris torrent was constructed to test the effects of disturbance (scour, deposit) and intensity (depth) on early patterns of revegetation. Both total cover and vegetative regrowth decreased with increasing intensity of disturbance, but no patterns in seedling establishment were observed. The expected responses (derived from assertions in the literature) were not completely supported by these results. This discrepancy indicates the danger in accepting hypotheses about successional recovery without adequate field testing.

PRIMARY KEYWORD: disturbance
SECONDARY KEYWORD: succession

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UNDERSTORY RECRUITMENT OF CONIFER SEEDLINGS ON VOLCANIC TEPHRA. D. B. Zobel, Oregon State Univ., Corvallis, and J. A. Antos, Univ. of Victoria, Victoria, B. C.

Seedling numbers of Tsuga spp. and Abies amabilis were counted on 15 cm deep tephra from Mount St. Helens and on excavated pre-eruption forest floor beneath 2 old-growth forests, by age class in 1980-1984 and 1987. Establishment of first-yr seedlings, survival, and number of >3-yr seedlings in 1987 were higher on natural tephra than on excavated plots. All measures of seedling success were higher on an herb-rich site with more light than beneath a denser, herb-poor forest, except that initial Tsuga establishment was higher on the herb-poor site (>150/m^2). Abies has more >3-yr seedlings than Tsuga in most situations, >23/m^2 on tephra at the herb-rich site. Seedling success was not correlated with microsite light intensity. Continued high survival will produce a dense coniferous understory at the herb-rich site.

51

GROWTH AND SURVIVAL OF EXPERIMENTALLY TRANSPLANTED POPULATIONS OF SIDALCEA NELSONIANA, A FEDERAL CANDIDATE SPECIES. R. J. Mishaga and J. L. Nicholls, CH2M HILL, Portland, Oregon, and McMinnville Water and Light Department, McMinnville, Oregon.

Studies were developed to determine whether Sidalcea nelsoniana could be propagated and transplanted successfully and could establish self-perpetuating populations. Approximately 1,400 greenhouse grown seedlings and 200 rhizomes from wild stocks were planted in 6 locations in the Oregon coastal mountains in 1986. Seedlings and rhizome survival rates in 1987 were 82.9 and 86.5 percent, respectively. Other information monitored included flowering, height, spread, seedling production, soil characteristics, and associated species. The high rates of initial transplant survival suggest that it may be feasible to establish new populations.

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SPROUTING OF PINK HEATHER IN RESPONSE TO FIRE. L. L. Potash
University of Washington, Seattle.

Vigorous sprouting of pink heather, Phyllodoce empetriformis, was documented after wildfires at 2 sites and the hypothesis that fire stimulates sprouting was experimentally tested at a third site. Six years after a wildfire, heather presence and cover were examined with respect to burning, litter depth, and proximity to forest. Three months after another wildfire, stem growth was compared on burned vs. unburned heather. At the experimental site, heather was measured and then received either a heavy burn, a light burn, clipping, or no treatment. Growth response will be assessed 1 year after treatment. Analysis of data from the wildfires suggest that heather cover and presence were reduced near the forest edge due to higher fire temperatures. Topkill seems to have less influence on recovery than ground heating. There was no significant difference in stem number of unburned vs. newly burned heather, suggesting initial rapid recovery.

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MORTALITY OF PONDEROSA PINE AFTER LOW INTENSITY PRESCRIBED FIRE AT CRATER LAKE, OREGON. D.M. Swezy. Univ. of Washington, Seattle.

Ten years of prescribed burning in a mixed-conifer forest were assessed to determine mortality levels of >22cm dbh ponderosa pine (pinus ponderosa Dougl.). Season of burn, tree vigor indices, and reconstructed fire severity estimates were the variables measured. Total mortality for a ten year period was higher in burned (19.5%) vs. unburned areas (6.6%) and for early season burns (3.5% in June, 29.3% in July) vs. late season (7.0% in Sept.). Discriminate analysis of mortality factors ranked height of crown scorch and depth of char as more important than tree characteristics such as diameter growth and crown vigor. Three-way chi-square analysis showed that crown vigor as described by Keen is related to mortality only for young or immature trees.

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AUTOPOLYPLOIDY AND TETRASOMIC INHERITANCE IN HEUCHERA GROSSULARIIFOLIA. P.G. Wolf, P.S.Soltis and D.E. Soltis. Washington State Univ., Pullman.

Heuchera grossulariifolia Rydb. (Saxifragaceae) is an herbaceous perennial native to the Pacific Northwest. Fourteen diploid ($2n=14$) and ten tetraploid ($2n=28$) populations from Washington and Idaho were analyzed using enzyme electrophoresis. Allele frequencies at 12 enzyme loci were used to estimate genetic distance among populations. Distribution of alleles among cytotypes and genetic distance data indicated that the tetraploid has evolved from the diploid at least twice. Controlled greenhouse crosses were made to examine inheritance patterns in the tetraploid. Tetrasomic segregation among seedling progeny was observed for four enzyme loci. Tetrasomy and the concomitant increase in heterozygosity in autopolyploid populations may provide a genetic basis for adaptation to habitats previously inaccessible to the diploid progenitor.

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A QUESTION OF IDENTITY AND ORIGIN OF A LAMIUM HYBRID NEW TO WASHINGTON STATE. Ronald J. Taylor and Joseph Arnett. Western Washington Univ., Bellingham, WA

A previously unreported species of Lamium was found by the authors in Skagit County Washington. The taxon was locally abundant, had a weedy habit, and occurred sympatrically with the diploid species, L. amplexicaule and L. purpureum. The new species proved to be tetraploid and was more or less intermediate in appearance between the diploids. To test the hypothesis of hybrid origin and subsequent allopolyploidy of the new taxon, phenetic (principal components) analyses, based on morphological variables, and comparative flavonoid studies were carried out. The results suggest that L. purpureum is a parental species but that L. amplexicaule is not. Based on our results and literature references, we conclude that the new taxon is Lamium hybridum and is a recent introduction from Europe.

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THE EFFECT OF THE 85% METHANOL EXTRACT OF ALNUS RUBRA (RED ALDER) ON THE SURVIVAL AND DIETARY UTILIZATION INDICES OF MALACOSOMA CALIFRONICUM PLUVIALE (TENT CATERPILLARS). A.B. Adams, University of Washington, Seattle.

The 85% MeOH leaf extract of red alder was separated into 4 subcomponents (water insoluble, non-phenolic water-soluble, monomeric phenols and condensed tannins) which vary in their ability to inhibit trypsin. Survival and growth of first instar is highest on agar diet with monomeric phenols which have moderate trypsin inhibition. Survival and growth is lowest on plain agar diet (control) and diet with condensed tannins, the latter being the subcomponent with the greatest trypsin inhibition. Efficiency of conversion of ingested matter to biomass (ECI) is highest on diets with non-tannin phenols, whereas ECI is never high on diets with tannins. Relative consumption rates are highest on diets with tannins. Caterpillar performance varies as a function of diet type, egg mass type and larval instar stage.

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A REPORT ON THE ECOLOGY OF THE OLYMPIC ENDEMIC, ASTRAGALUS COTTONII. M.B. GRACZ, T.N. KAYE and E. SCHREINER.

A rare endemic of the Olympic Mountains, Washington, Astragalus cottonii M.E. Jones, is investigated to describe habitat requirements, and extent and fullness of distribution. Reconnaissance plots were placed in A. cottonii habitat and the resulting abiotic and biotic data compared with identical plots placed throughout the NE Olympics in similar subalpine habitat. Analyses using TWINSPAN, DCA and other multivariate techniques indicated that A. cottonii habitat could be distinctly characterized and that the plant appears to fill most of its potential habitat. Further work is being carried out to investigate the plant's population biology, edaphic restrictions, taxonomy and ecology.

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PHYTOGEOGRAPHIC STUDIES OF PACIFIC COASTAL DISJUNCT PLANTS IN THE NORTHERN ROCKY MOUNTAINS. C.C. Lorain and F.D. Johnson. Univ. of Idaho, Moscow.

Strong maritime influences have promoted development of Thuja plicata-Tsuga heterophylla forests along the western slopes of the Northern Rocky Mountains. Within these forests reside small popuations of disjunct taxa with Pacific coastal affinities, such as Cornus nuttallii, Alnus rubra, Gaultheria shallon, and Ribes sanguineum, as well as numerous other species. Analyses of present distributions patterns, coupled with paleoclimatic and palynologic evidence, reveal that some of these species are apparently Miocene relics while others appear to be post-Pleistocene invaders. We hypothesize four plausible migration routes to explain the distribution patterns of these disjunct plant taxa.

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PHENOLOGY OF SPRING FLOWERING PLANTS IN EUGENE, OREGON. David H. Wagner. University of Oregon, Eugene.

I have been leading plant walks in Alton Baker Park, Eugene, Oregon, since 1977. We have noted the time of first flowering for 195 different plants. Not all these have been observed every year, only half being observed regularly. Exotic, weedy annuals are most sporadic in appearance. The native annuals, however, are surprisingly irregular in their appearance. The patterns which have emerged show that native plants are generally more sensitive to environmental variation than introduced plants. This can be demonstrated in a single genus, Rubus, where the native species has one of the highest variations from year to year and the introduced species blooms within a week of the same day each year.

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SPERM CELLS FROM FLOWERING PLANTS: STRUCTURE AND ISOLATION. D. Southworth. Southern Oregon State College, Ashland.

In flowering plants, sperm cells are embedded in the vegetative cell of pollen grains or pollen tubes. Sperm cells were isolated from pollen of Gerbera jamesonii (Asteraceae) by methods adapted from procedures for organelle isolation. Their structure was determined by fluorescence microscopy, and by scanning and transmission electron microscopy. They are elongate cells with a compact nucleus and reduced cytoplasm. Isolated sperm cells will be useful in understanding the process of double fertilization in plants.

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PHYLOGENETIC IMPLICATIONS OF SEED MORPHOLOGY IN CALOCHORTUS (LILIACEAE). B. D. Ness. Dept. of Botany, Washington State University, Pullman.

Seed surface morphology of 37 species of Calochortus was examined using the scanning electron microscope. Two major seed types were found. "Calochortus" type seeds are irregular in shape with roughly tetragonal to irregular integument cells lacking secondary thickenings in the outer cell walls. "Mariposa" type seeds are flattened and lenticular in outline with roughly hexagonal to irregular integument cells which have peripheral secondary thickenings in the outer cell walls. Calochortus type seeds were found in all investigated members of section Calochortus and in one species (C. barbatus) of section Cyclobothra. Mariposa type seeds were found in all investigated members of section Mariposa and in subsection Weediani of section Cyclobothra. Prior gross morphological evidence coupled with evidence from this study suggests that section Cyclobothra, as it is now delimited, is polyphyletic.

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PRODUCTION OF MONOCLONAL ANTIBODIES AGAINST *Corynebacterium diphtheria*. L. J. Beck and C. T. McNutt. Eastern Washington Univ., Cheney.

Balb/c mice were immunized with heat killed and sonicated *C. diphtheria* cells. The mice were bled every two days and the serum was tested for the presence of anti-*C. diphtheria* immunoglobulin by ELISA techniques. When levels became detectable, two mice which had the highest titre of antibody were sacrificed. The cells were then harvested from the spleens and put into culture with heat killed *C. diphtheria* whole cells for further boosting. After four days the immunized cells were fused with NS-1 mouse myeloma cells, and the resultant hybridomas were put into culture. When cloning hybridomas were evident, isolation of single hybrid cells by limiting dilution was used to provide monoclonals. These monoclonals were then tested by an ELISA for anti-*C. diphtheria* immunoglobulin production. The four monoclonals that yeilded positive results are most likely against surface antigens and may have cross reactivity to pathogenic strains of *Corynebacterium* which could be useful in clinical diagnosis, identification, and structural studies.

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BIOAESTHETICS AND INTEGRATED LEARNING. F. D. Shepard, Southern Oregon State College, Ashland

Bioaesthetics is proposed as a new field of study which explores human aesthetic ties to nature. Its foundation is the view that human evolution provides a genetic tendency for aesthetic ties to our natural surroundings, including each other. It is argued that through formal and informal education the strengthening of these ties is a prerequisite for any adequate expression and application of an environmental ethic.

It is also argued that in today's world the cultivation of human aesthetic tendencies and expressions, particularly in technology-based societies, is neglected.

Bioaesthetics can become a promising tool in integrated formal education at all levels, serving as an antidote to negative aspects of the compartmentalized and fragmented curricula at many levels of contemporary schooling.

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A SELECTIVE ANALYSIS OF NATURAL RESOURCE-BASED EDUCATION: BARRIERS, FIELD PROJECTS AND CURRICULUM MODELS. L.K.Hilligoss. Siskiyou Environmental Education, Ashland and B.A.Middleton. Oregon State University, Corvallis.

Research on common barriers faced by educators incorporating Environmental Education into their curriculum. A selection of activities enhancing the scientific method in K-12 classrooms. National efforts combining scientific research and hands-on activities resulting in field projects. Demonstration of current cross curricular natural resource-based programs such as the Oregon Forestry Education Program and Project Wild.

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INTEGRATED SCIENCE CONCEPTS COURSES FOR PRE-SERVICE ELEMENTARY TEACHERS OF SCIENCE. Don W. Mitchell. Southern Oregon State College, Ashland.

A pilot program preparing pre-service elementary teachers to teach science has been developed and is being tested at Southern Oregon State College. Faculty of the Schools of Science and Education and a cadre of practicing teachers in local schools have developed and tested the materials and techniques used in the courses for the past two years.

Students are enrolled in a four-hour integrated science concepts course for each of the three terms. A limited number of concepts that are pervasive in grades K-6 serve to unify the interdisciplinary approach. Hands-on, concrete, beginning with the familiar, characterize the sequence. After broadening their understanding of the processes, content and concepts, students develop lessons that are adaptable for the handicapped and non-handicapped. They then present lessons in K-8 classrooms of the cadre of science-oriented practicing teachers.

Evaluations indicate that the confidence, enthusiasm and competence of the pre-service teachers to teach science has been substantially increased.

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EFFECT OF BEDROCK TYPE ON GEOCHEMISTRY AND VEGETATION

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This paper is an overview of the influence of bedrock geology on the geochemistry and vegetation of an area. This is not original work, rather, examples are taken from the literature. Ultramafic rocks are stressed because they serve as good examples, and they are common in Oregon. Soils developed on ultramafic rocks inhibit or completely prevent growth of vegetation. Spring waters draining ultramafic rocks are enriched in magnesium bicarbonate and show average pH values of 8.7. Unusual calcium-hydroxide waters with pH values as high as 11.7 are observed at some springs. The reasons for these effects and the consequences on resource assessment are discussed. It is concluded that geology and geochemistry play an important and sometimes subtle role in the development of vegetation, and that vegetation, like beauty, is only skin deep.

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UNIQUE FOSSILS AND PSEUDOFOSSILS FROM WASHINGTON AND BRITISH COLUMBIA. W.R.Danner. Univ. of British Columbia, Vancouver,Canada

Washington and British Columbia contain several unique fossils and pseudofossils some of which are very useful for interpreting age and environment, others of which remain a mystery. Most striking and geologically useful are the Late Permian Tethyan fusulines which deliniate the Pacifica exotic terrane. Others are the strange tube fossils formerly called Terebellina, now recognized as the foraminifer Bathysiphon found in the Olympics and western Cascade Mountains foothills, and the large palm fronds of the Eocene Chuckanut Formation. The Bear River Limestone of SW Washington composed of deep water pelecypods and an unknown encrusting organism is the only deep water limestone mound known in the Pacific Coast Tertiary. The siderite pseudocoprolites of the Miocene Wilkes Formation near Toledo, Wash. have long been a subject of controversy as to their origin. The most recent discovery is a large pseudofish fin.

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LATE-PLEISTOCENE PLUVIAL HISTORY OF THE ALVORD BASIN, HARNEY CO. OREGON. D.N. Lindberg Humboldt State University, Arcata, CA and M.A. Hemphill-Haley Woodward-Clyde Consultants,Oakland CA.

To determine the nature and extent of late-Pleistocene pluviation in the Alvord Basin, elevations of prominent paleo-shorelines were measured in the field. Basin closure was then evaluated by inspection of topographic maps. Well-defined shorelines at elevations of 1310m and 1280m are tentatively correlated to pluvial events in the Lahontan Basin to the south. During a late-Pleistocene pluvial cycle, a rising Lake Alvord breached a low point in the Tule Springs Rim at an elevation of 1310m and spilled into the Coyote Lake Basin to the east. The water level in Coyote Lake Basin is regulated by a sill on the east side of its basin at an elevation of 1278m. Water from Coyote Lake flowed east into Crooked Creek, an Owyhee River tributary. The water draining from Lake Alvord downcut through the Tule Springs Rim until the water level in both basins had equilibrated at about 1280m. Big Sand Gap, a modern wind gap in the Tule Springs Rim, is the result of Lake Alvord breaching the Tule Springs Rim and draining rapidly into Coyote Lake Basin. Big Sand Gap served as a sill at 1280m during post-breaching Pleistocene pluviations in the Alvord Basin. Thus, any post-breaching pluviations in the Alvord Basin were constrained to a maximum elevation of about 1280m by the sill at Big Sand Gap. Lake levels in the Coyote Lake Basin were constrained to an essentially equivalent, maximum elevation of about 1278m. The estimated uplift rate along the eastern escarpment of Steens Mountain and Holocene alluvial fan deposition in Big Sand Gap make the 2 meter discrepancy in sill elevation negligible.

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TECTONIC DEFORMATION OF LATE PLEISTOCENE SHORELINES IN WARNER VALLEY, LAKE COUNTY, OREGON. Gilbert F. Craven, Department of Geology, Humboldt State University, Arcata, Ca, 95521

Shoreline elevations were measured using leveling survey transects along the eastern and western sides of Warner Valley south of Hart Mountain, in order to construct a three-dimensional model of regional deformation. Shoreline ages were interpreted by correlation to the Lahontan stands outlined by Benson and Thompson (1987). While the eastern shorelines show no deformation within the precision of the survey, the western shorelines show 33M of deformation down to the North, constrained to a distance of approximately 8 km. This deformation is interpreted as regional warping, largely due to the absence of latest Pleistocene - Holocene fault scarps. The uppermost shoreline is believed to be a12.5ka -13.5ka shoreline. Lower shorelines show, in addition to this warping, varying amounts of deformation reflecting arching during their formation, and are assigned 15ka and 16.5 ka ages. This implies a period of arching prior to 13.5ka and monoclinal warping post 12.5ka. The apparent locus of warping coincides with the epicenters of the 1968 earthquake swarm determined by Schaff (1976).

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THE PETROLOGY OF THE SUMMIT VALLEY PLUTONIC COMPLEX, KLAMATH MOUNTAINS, CALIFORNIA. D. B. Parker. Humboldt State Univ., Arcata .

Near Summit Valley, Jurassic Galice and Lem's Ridge metasediments are juxtaposed against the basal ultramafic tectonic melange of the Late Triassic Rattlesnake Creek terrane by the Orleans fault. The Orleans fault is a regional structure which separates the western Paleozoic and Triassic belt from the underlying western Jurassic belt. The Summit Valley pluton is a mafic-rimmed, hornblende- pyroxene diorite intrusion which cuts both thrust plates. Intrusive rocks lack the foliation and greenschist metamorphism observed in upper plate peridotites and lower plate metasediments. This suggests that pluton emplacement postdates development of the Orleans fault during the Nevadan orogeny. Near the pluton, siliceous argillites and conglomerates of the Lem's Ridge olistostrome are altered to hornblende hornfels. The upper plate intrusive contact is defined by a narrow hybrid zone containing partially resorbed xenoliths of peridotite and rare amphibolite gneiss. Hornblende pegmatites along the western edge of the pluton, and hornblende rims along small-scale intrusive contacts indicate widespread Ca metasomatism. Andesite dikes and sills and extrusive and pyroclastic clasts within Lem's Ridge conglomerates suggest deposition in an island arc setting.

71

A FIFTH LEAVENWORTH SUBSTAGE IN THE ICICLE-CHIWAUKUM CREEKS AREA, NORTH CASCADE RANGE, WASHINGTON. W.A. Long, 123 Riverfront Dr., Cashmere, WA 98815

The Chiwaukum Creek valley-head Larch Lake moraine, in the North Cascade Range of Washington, reaches 5700 feet altitude and lies between moraines of Leavenworth IV (Rat Creek) age and Neoglacial moraines. On and behind the Larch Lake moraine 12,000 yr old Glacier Peak tephra is present beneath 6900 yr old Mazama ash. Icicle Creek, which lies south of Glacier Peak tephra limits, has moraines with preservation, topographic position and expression identical to that of the Larch Lake moraine. As the Larch Lake moraine evidently correlates with Icicle Creek moraines, it most likely represents a formerly unrecognized fifth and apparently final fluctuation of Leavenworth ice.

72

FUMAROLE FIELDS AND THERMAL FEATURES AT MOUNT HOOD, OREGON. K.A. Cameron, U. S. Geological Survey, Cascades Volcano Observatory, Vancouver, Washington.

Thermal features are restricted to two main fumarole fields and numerous isolated vents and patches of warm ground near the composite dacitic dome called Crater Rock. The Hot Rocks field north of Crater Rock covers about 8000 m^2 of warm-to-hot ground and contains relatively few active vents. The Devils Kitchen field to the south of Crater Rock covers about 4000 m^2 and contains numerous active vents, many of which are actively precipitating crystalline sulfur. No ground or vent temperatures were found that exceeded local boiling (91° C). In both fields the host rock has been reduced to sticky, blue or grey clay. Gas composition has remained essentially constant since the first analysis in 1935. Historical accounts and photographic evidence indicate that the Devils Kitchen field increased activity around 1890 A.D., dramatically altering the surrounding glacial systems and separating Coalman Glacier from White River Glacier. Vent temperatures may have been super-heated at that time.

73

AN ALLUVIAL FAN, A PEDIMENT, AND TECTONISM OF EARLY MIOCENE AGE, SUTTON MOUNTAIN, WHEELER COUNTY, OREGON. I.R. Gordon and E.M. Taylor, Oregon State Univ., Corvallis

At Sutton Mountain, the Haystack Valley Member of the John Day Formation is an alluvial fan deposit. It coarsens upward from claystone to channel deposits and debris flows, then passes into a sequence of paleosols intercalated with infrequent clastic beds. Excepting a few ignimbrite pebbles in its upper half, all clasts within the fan deposit are tuffaceous claystones derived from older John Day Formation tuffs. After fan deposition, a period of net erosion produced a northwest-dipping pediment. Clast compositions and size distributions suggest that the pediment's cover gravel originated from an upfaulted ridge along the Richmond Fault (Fisher, 1967). Deformation along this fault included the vertical positioning of at least 700 meters of Clarno and John Day formation tuffs and lava flows. Syntectonic fan deposition, followed by pedimentation, occurred in the early Miocene, before the fault and pediment were overlapped by the Picture Gorge Basalt.

74

DEVELOPMENT OF A CHRONOSEQUENCE OF SURFACES ON AN ALLUVIAL FAN IN THE OWENS VALLEY. J.F. Herrick. Humboldt State Univ., Arcata.

The surfaces of the alluvial fan deposits of Birch Creek drainage in the Owens valley, California, exhibit a range of ages (chronosequence). This chronosequence of fan surfaces is expressed by the degree of weathering seen on the individual granitic boulders and the morphology of the surface itself. Detailed multiparameter Relative Dating techniques were used to quantify differences between surfaces which were initially delineated using remotely sensed Thematic Mapper images. Eight seperate surfaces are recognized on the Birch Creek fan. Interfingering relationships with K/Ar dated basaltic lava flows permits better age estimates for several of the surfaces. These fan surfaces range in age from historic to an estimated 1ma. and the times of deposition appear to be widely separated. Based on observed field relationships, the depositional history of the fan consists of long periods of little deposition punctuated by brief pulses of major deposition. It has been suggested that these brief periods of deposition occured during times of deglaciation. Each depositonal pulse was very extensive and covered most older deposits except where those deposits are removed from further input by being uplifted and isolated by local fault displacement.

75

NEW DATA FOR LARGE, LATE HOLOCENE DEBRIS FLOWS IN THE PUYALLUP BASIN, WEST OF MOUNT RAINIER, WA. P.T. Pringle, U.S. Geological Survey, Cascades Volcano Observatory, Vancouver, WA.

During the past 3000 years, at least three large debris flows inundated parts of the Puyallup River flood plain in the Puget Sound Lowland. After 2740 yr B.P., a noncohesive (<3% clay) lahar was probably triggered by eruption-induced snowmelt and flowed at least 43 km from Mount Rainier. About 1310 yr B.P., a noncohesive debris flow containing abundant glacial-outwash sediment and bedrock megaclasts left deposits as far as 43 km from Mount Rainier. This flow may have been generated by a lake breakout. Deposits of the cohesive (>3% clay) Electron Mudflow of Crandell (about 550 yr B.P.) overlie the outwash-rich deposits 30 and 18 meters above the present valley bottom 37 and 43 km from Mount Rainier. Base of the Electron is about 15 and 8 m below modern valley bottom at these sites. Peak discharge at Electron was about 270,000 m^3/s.

76

ANALYSIS OF KAMES COMPOSED OF FINE GRAINED SEDIMENT, WATERVILLE PLATEAU, WASHINGTON.
B.A. May, P.K. Spencer, and R.J. Carson, Whitman College, Walla Walla.

The Waterville Plateau contains at least four large kames (about 100-400m in diameter) consisting of fine grained, fairly well sorted ice-contact stratified drift deposited by the Okanogan Lobe of the Cordilleran Ice Sheet. The study involves qualitative and quantitative analysis of landforms and sediments with the intent of determining possible modes of origin. The kames are associated with topographic basins and with eskers. The fine to medium grained sand of the kames has silty interbeds with planar bedding and climbing ripples. The kames have a till cap consisting of silt, sand, and a few pebbles, cobbles, and boulders. These features suggest a lake (possibly subglacial) surrounded by stagnant ice in which rapid deposition of sand, silt, and finally till occurred.

77

GEOLOGY OF THE NORTHERN PORTION OF THE LIKELY FAULT LINEAMENT, MODOC COUNTY, NORTHEASTERN CALIFORNIA. S.L. Potter Humboldt State Univ., Arcata.

An investigation of the northern portion of the Likely fault lineament was conducted to determine its degree of activity and seismic potential. Previous reports indicate that the fault may be a right-lateral strike-slip Quaternary feature. Geologic mapping of the northern 10 miles of the Likely lineament revealed no evidence of major faulting. Rather, field evidence suggests that this portion of the Likely lineament is the surface expression of tilted beds. Differential erosion of a thick sequence of tuffs and flows (N45W, 40NE) in the Cooley Gulch area has produced linear ridges and valleys that are visible on high altitude air photos and Landsat imagery. Fracture analysis of normal-oblique slip faults in the Plio-Pleistocene Alturas Formation indicates northeast-southwest extension. The overlying Devils Garden basalts are horizontal and unfaulted. Extensional features observed in the study area suggest listric normal faulting. Fault patterns and geomorphic features may fit clay cake models of Basin and Range normal and cross faulting. Historic seismicity indicates that the Modoc Plateau is seismically quiet and that normal faults are either inactive or active with a large recurrance interval.

78

A FOREST PLANTATION GRAZING STUDY IN THE CENTRAL WASHINGTON CASCADE RANGE: MUSINGS OF A SCIENTIST/HERDER.
P.J. Edgerton. USDA Forest Serv., Pacific Northwest Res. Stn., Wenatchee, WA 98801.

Short-duration sheep grazing is being evaluated as a tool to suppress early development of Acer circinatum, Ceanothus velutinus, and other seral vegetation in recent clearcuts on the east slope of the Cascade Range. During August and September 1987, 1100 adult ewes were grazed in unplanted clearcuts and in 2- and 3-year-old Pseudotsuga menziesii plantations. Vegetation characteristics, forage availability and use, and tree-seedling damage were measured. First-year results showed that grazing may be an effective site-preparation treatment where planting has been delayed. In established plantations, grazing was most effective in 2-year-old units, especially on gentle slopes. Sheep preferred grasses, forbs, and Acer circinatum. Tree seedling damage was minimal where animals were carefully managed. The need for close cooperation of land managers, the livestock owner, and the herder in planning, implementing, and monitoring grazing is emphasized.

78

MALE CHAUVINISM IN FORAGING STRATEGIES OF THE SEA OTTER, ENHYDRA LUTRIS. Sullivan, Heather I., University of Washington, Seattle, and Sullivan, John O., Southern Oregon State College, Ashland, Oregon.

Four captive sea otters at the Point Defiance Zoo, Tacoma, Washington, were provisioned with oysters. As tool users, the female sea otters pounded the oysters against another oyster, which rested on their chests. All three females engaged in this pounding activity, which resulted in cracking the shells of the oysters and rendering the nutrient payoff available to the otters. The male (a good third larger than the largest female) did little pounding; he simply took the available oyster body from the females after they had cracked the shells. The larger, more powerful male sea otter took advantage of the time and energy expenditures of the females.

79

PHYSICAL, VISUAL, AND TEMPORAL CHARACTERISTICS OF PERCH SELECTION AND USE BY CERYLE ALCYON. Matthew W. Snook, and John O. Sullivan, Southern Oregon State College, Ashland, Oregon.

The Sycan River, a tributary of the Klamath River in south central Oregon, provides a varied habitat for the belted kingfisher, Ceryle alcyon. The river is used for foraging throughout the year, except when frozen. Upon arrival in the spring, the birds are not distributed evenly or permanently across the available habitat, nor is use by the birds consistent from day to day. A search for factors influencing foraging behavior spans a diverse range of characteristics from the attitude of the sun to the nature of the stream substrate.

80

RELATIONSHIP OF CONVECTION FOG TO VEGETATION OF REDWOOD NATIONAL PARK, CALIFORNIA. S.A. Harris. Humboldt State Univ., Arcata, California.

The relationship of the distribution of three redwood (*Sequoia sempervirens*) vegetation communities (Defined by James Lenihan, Humboldt State Univ., Arcata, Calif.) with fog/stratus coverage frequencies was explored, using Step-Wise Discriminant Analysis. Fog/stratus coverage of September was the dominant dimension of discriminant functions. Discriminant functions were tested with classification of an independent vegetation data set. The *Sequoia sempervirens/Blechnum spicant* vegetation type, which represents redwood stands with the greatest basal area and canopy closure, was accurately classified by classification functions developed with variables of fog/stratus coverage in September. Soil moisture was lowest in September. In the presence of fog/stratus, reduced evapotranspiration stress, and absorption of moisture by redwood leaves may provide redwoods with competitive advantage. Fog/stratus supports the establishment and growth of redwood and associated vegetation communities, whereas, dominant control of the distribution of redwoods appears to be soil moisture.

81

FOLIAR PENETRATION AND VOLATILIZATION OF TRICLOPYR BUTOXYETHYL ESTER FROM DEPOSITS ON LEAVES AND GLASS SLIDES. K.P.Bentson and L.A.Norris. Oregon State University, Corvallis.

Short-term dissipation of triclopyr butoxyethyl ester herbicide from Pacific madrone leaves, giant chinkapin leaves, and glass microscope slides in the dark was measured. Factor levels of 3 temperatures (10, 25, and 40° C), 3 surfaces, and 6 times (0, 816, 1632, 2448, 3264, and 4080 minutes) were used with measurements of nanomoles of triclopyr that are either absorbed by the leaf, remaining in the surface deposit, or lost. Greatest foliar penetration occured at 40° C in chinkapin. Volatilization from leaves was greatest at 25° C. Pseudopartition coefficients were used to model foliar penetration and volatilization.

82

HISTORICAL RECONSTRUCTION OF THE AMOUNTS OF LARGE WOODY DEBRIS AT NORTHWEST RIVER MOUTHS. P.A. Benner and J.R. Sedell. Oregon State Univ., Corvallis and U.S.D.A. Forest Service, PNW Research Station, Forestry Sciences Lab, Corvallis, OR.

Historical records of northwest U.S. coastal rivers from the mid-1800's documented extensive "heavy drift" and freshet transported old growth trees in tidal reaches. Large wood functioned in spit and bar formation, as nurse logs for Sitka spruce, and habitat diversity enhancement. Present day lengths and volume of wood are significantly smaller. A fifteen year chrono-sequence of aerial photographs of four Oregon river mouths has shown a 70% reduction of wood volume since 1970. Historically, sources of wood included landscape-wide creek to estuary inputs. Deforestation of once wooded riparian corridors diminished these sources. Changes in forest practices and firewood collection are recent factors contributing to the reduction of drift reaching and accumulating at river mouths. Logged timber is not as commonly transported and stored in coastal rivers. Cumulative losses of large woody debris has impacts on wetland and aquatic community structure.

83

SPATIAL AND TEMPORAL PATTERNS OF OZONE IN WESTERN WASHINGTON FORESTS. F.A. Basabe and R. Edmonds. University of Washington, Seattle.

Continuous ozone measurements were made at 10 sites (6 forest, 4 rural) in western Washington during the 1985-87 growing seasons. Ozone concentrations exceeding the National Air Quality Standards (120 parts per billion) were measured at one or more sites during each growing season. These excessive concentrations occurred downwind from major urban areas where ozone levels were below the national standard. Apparent ozone symptoms have been observed on conifers where high ozone concentrations were measured.

84

ESTIMATING SALMON PRODUCTION AT A SPAWNING CHANNEL ON THE SACRAMENTO RIVER. T.J. Hassler and S.A. Spaar, CA Coop. Fish. Unit, Humboldt State Univ., Arcata.

The development of water resources in northern California has caused a significant loss of spawning and nursery habitat for chinook salmon in the Sacramento River. The Fish and Wildlife Service is involved in efforts to mitigate for the loss of spawning habitat due to the construction of Red Bluff Diversion Dam on the river. Only part of the young salmon leaving the spawning channels pass through the electronic counting station at the channel's downstream terminus. The remaining young "roll over" the rotating drum screens and are not counted. We developed a sampling program to estimate the numbers and sizes of chinook salmon larvae and fry leaving the spawning channels by "roll over" with a fyke net and live box combination from January through March 1984-85. The main factors influencing the catch were turbidity, time, and date. We estimated that 12% of the production in the channels escaped in 1984 and 20% in 1985. Most fry that escaped from the channels were less than 40 mm long. Lighting the screen complex at night appeared to have a dampening effect on the migration of fry.

85

EARLY SCIENTIFIC EXPEDITIONS ON MOUNT SHASTA. S.R. Mark, Ashland Oregon.

Mt. Shasta's historical importance to science has been substantially understated. Three investigations there in the last century are relevant to present understanding of the interface between glaciology and biogeography. Summarized are: Clarence King's discovery of "living glaciers" on Shasta in 1870; the Hooker-Gray Expedition of 1877; and the application by C. Hart Merriam of his life zone theory to the mountain in 1899.

86

WATER RESOURCES PLANNING IN OREGON: A BOLI NEW DIRECTION. Claude W. Curran, Southern Oregon State College, Ashland, OR 97520.

The Oregon Water Resources Commission has embarked upon a bold new approach regarding water policy issues. The Commission has developed a process wherein each of twelve resource agencies will develop biennial management plans. The plans wil be prioritized by the commission and lead agencies will be designated. Other agencies will cooperate and coordinate with the lead agencies' plans. Analysis of al the plans will provide a program that can be placed before the legislature during the start of each biennium. The Water Resources Commission will play a more active role in support of desired legislation. This approach holds the promise of coordinated management for one of the state's critical resources.

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NORTHWEST SCIENCE

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Demise of the Collision Theory

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Announcements

Review Article—Dinosaur Extinctions

Dinosaurs died out over 65 million years ago, yet their presence lingers in imagination, in Walt Disney animations, in scenarios about a nuclear winter. Everyone seems to have a claim on these overgrown reptiles. Anyone that can round up a congregation or a press corps seems to find in the extinction of the dinosaurs a parable for modern society. We are told that they met a sudden demise. We tend to think of weeks, a few years, perhaps a century. Yet the extinction of the dinosaurs was sudden only in geological terms. Perhaps a million years or more. In human terms, that is a long time. Other animal species accompanied dinosaurs into biological oblivion. Many did not. The picture is complex.

Perhaps for all these reasons, when, a few years ago, collision with a meteor or an asteroid was proposed as the cause of dinosaur extinctions, the theory was met with eager acceptance. A troubling old mystery had been solved. But, all this has proved to be too easy of an answer to a complex question.

I am thus pleased to provide a review of this subject in this issue, prepared by Drs. Charles Drake of Dartmouth University and Yvonne Herman of Washington State University. They share with us the reasons for being suspicious of these impact theories of dinosaur extinctions and point to a more promising alternative, extended volcanic activity and its effects on the atmosphere. As Dr. Drake has said before, theories about the impact of impacts on the nature of nature go back a long way in human history. That is where their review article begins. I hope you will find it as enlightening as I did.

—editor

MEETING OF INTEREST

The International Mountain Logging and Pacific Northwest Skyline Symposium will be held in Portland, Oregon on December 12-16, 1988. Intended topics include any aspect of timber harvesting and transportation in mountainous areas, with an emphasis on steep terrain operations. Papers (title and an abstract of 300-500 words) or poster (topic and short 200 word description) should be sent by October 1, 1987 to: William A. Atkinson, Program Committee Chairman, Department of Forest Engineering, Oregon State University, Corvallis, OR 97331.

Bradley T. Piehl,[1] **Robert L. Beschta,** and **Marvin R. Pyles,**
Department of Forest Engineering, Oregon State University, Corvallis, Oregon 97331

Ditch-relief Culverts and Low-volume Forest Roads in the Oregon Coast Range[2]

Abstract

Drainage systems associated with gravel-surfaced roads often rely on culverts for moving water through the road prism and for minimizing onsite erosion. The purpose of this study was to determine the characteristics and functional capabilities of ditch relief culverts (DRC's) in the Coast Range of western Oregon. Five hundred and fifteen DRC's were evaluated to determine diameter and length, spacing, inlet conditions, skew angle, slope, and outlet erosion. Most DRC's (86%) were corrugated steel pipe. Pipe diameters were typically 38.1 or 45.7 cm (15 or 18 in.); average length was 10.7 m (35.1 ft.). Cross-sectional area of 74 percent of the inlets had been reduced by sediment deposition, pipe damage, cutbank sloughing, or organic debris; the inlet area of all DRC culverts averaged 81 percent of original. Spacing of DRC's varied by ownership category, with averages of 2.6 to 5.2 DRC's per km (4.2 to 8.4 per mi). Ditch erosion was minimal except with relatively long culvert spacing. Erosion at culvert outlets increased with culvert spacing.

Introduction

Low-volume roads (typically single-lane, gravel-surfaced roads with little traffic) are an essential component of managed forest lands throughout the western United States. Culverts provide the most common means for moving water across these roads and represent an important aspect of the overall design and operation of an effective forest road-drainage system. Road drainage not only influences road surface and ditch erosion, but in steep terrain it also can affect the occurrence of fillslope failures (Burroughs 1984). Direct costs associated with these failures include loss of use of the road and the expense of replacing the culvert and its associated fill. In addition, road failures represent an important management concern, because of their potential for directly impacting aquatic habitat and water quality of streams. Dyson *et al.* (1966) evaluated damages on U.S. Forest Service lands in the Pacific Northwest after major storms in December 1964 and January 1965. They concluded that failure of road-drainage facilities caused nearly all road damage and that plugged ditch-relief culverts contributed significantly to this problem.

More recently, Krag *et al.* (1986) completed a detailed analysis of thirty-one slope failures associated with logging roads on the Queen Charlotte Islands in Canada. Most of these road-associated failures were traced to problems of road drainage: the absence of ditches or ditches formed from road ballast, culverts that were spaced too far apart or poorly located, and culverts that were too small.

Forest roads typically intercept part of the subsurface flow moving down a slope and route it along a ditch until the water is diverted across the road. Surface runoff from insloped portions of the road adds more water to the ditch. In most cases, water diversion is accomplished with a ditch-relief culvert (DRC), also called a cross-drain culvert. The contributing area for DRC's is often small and poorly defined by surface topography.

Design of a DRC system (Figure 1) includes culvert spacing (uphill distance to the next culvert or grade break); ditch, inlet, and outlet geometry; and culvert diameter, slope, and skew angle. The basic objective is to provide stable drainage at lowest cost. This requires a tradeoff between initial installation cost and potential for future costs of road failure and environmental damage. However, economic costs of failure and environmental damage remain difficult to quantify.

In general, wider spacings result in more water flowing in the ditch, through the culvert, and discharging downslope. Greater amounts of water increase the potential for ditch and road-

[1]Currently with Riverside Technology, Ft. Collins, CO 80525.

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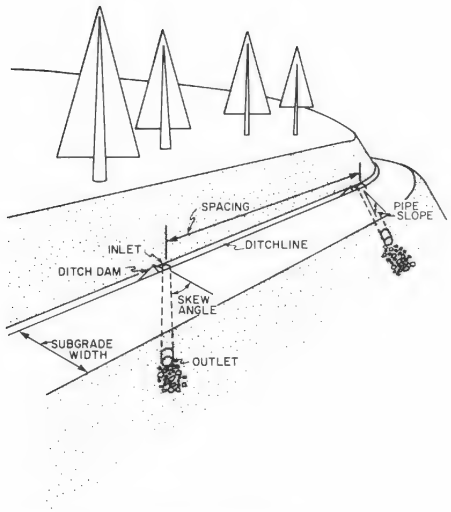

Figure 1. Ditch-relief culvert system.

surface erosion and for erosion of the fillslope or the natural slope below the culvert outlet. Any of this erosion could lead to complete road failure.

Culvert plugging can lead to road-surface or gully erosion by water flowing on the road; catastrophic failure of fill or sidecast material; or water continuing down the ditch, to be diverted by the next DRC. Efficient inlet geometry, large culvert diameter and steep slope, and large skew angle are believed to increase hydraulic efficiency and reduce the occurrence of plugged culverts.

Arnold (1957) presented spacing guidelines developed in 1953 for U.S. Forest Service DRC's. These guidelines were based on his experience with road drainage structures in the Cascade Mountains of the Pacific Northwest. Control of ditch erosion was a major objective. Arnold's recommended spacing was a function of soil erodibility and road grade (Figure 2). Hillslope soils were categorized in ten erosion classes. Basic culvert spacing was adjusted by a rain-intensity factor based on the 25-year, 15-minute storm; higher rain intensity calls for closer spacing.

Baeder and Christner (1981) adjusted Arnold's spacing guidelines to provide closer spacings for most culverts in the Willamette National Forest in the Oregon Cascade Mountains by including slope position, aspect, and cutbank failure probability, but their revisions are not based on field data or a theoretical model.

This study was undertaken to determine the characteristics and functional capabilities of existing DRC's in the Oregon Coast Range and to determine the design provisions that appear to optimize performance. No ditch or outlet erosion and a clear inlet and culvert barrel were assumed to indicate optimum performance.

Study Area

The central Oregon Coast Range (in Lincoln, Benton, Lane, Douglas and Coos counties) is underlain by the relatively homogenous Tyee sandstone formation; soils therefore are of similar erodibility. Landforms are steep (up to 100% slope), with highly dissected hillslopes and sharply formed ridgelines. Annual precipitation (primarily rain) is high, ranging from about 180 cm (70.9 in.) near the coast to over 300 cm (118.2 in.) along the crest of the Coast Range. Nearly 80 percent occurs from October through March, when frontal storms often continue without interruption for several days. Daily rainfall amounts of 13 to 18 cm (5.1 to 7.1 in.) occur, on the average, about once every 10 years in the study area (Miller *et al.* 1973). Drainage densities are relatively high, averaging nearly 6.2 km of stream/km^2 (10.0 mi/mi^2) of watershed (G. S. Bush, unpublished data). Road densities on U.S. Forest Service lands average 1.6 km/km^2 (2.6 mi/mi^2), because the road system is not yet complete; road densities are generally greater for other ownerships.

Methods

Within the study area, three sections were randomly selected from each township. Within each section, all roads were divided into segments, where a segment represents the length of road between two intersections, or between an intersection and the end of the road. The segments were numbered and three of them were randomly chosen for examination. Culverts were selected by going to the nearest end of a selected road segment and examining the first six culverts encountered along that segment.

Since culverts were selected in sequence along a road segment, there is some opportunity

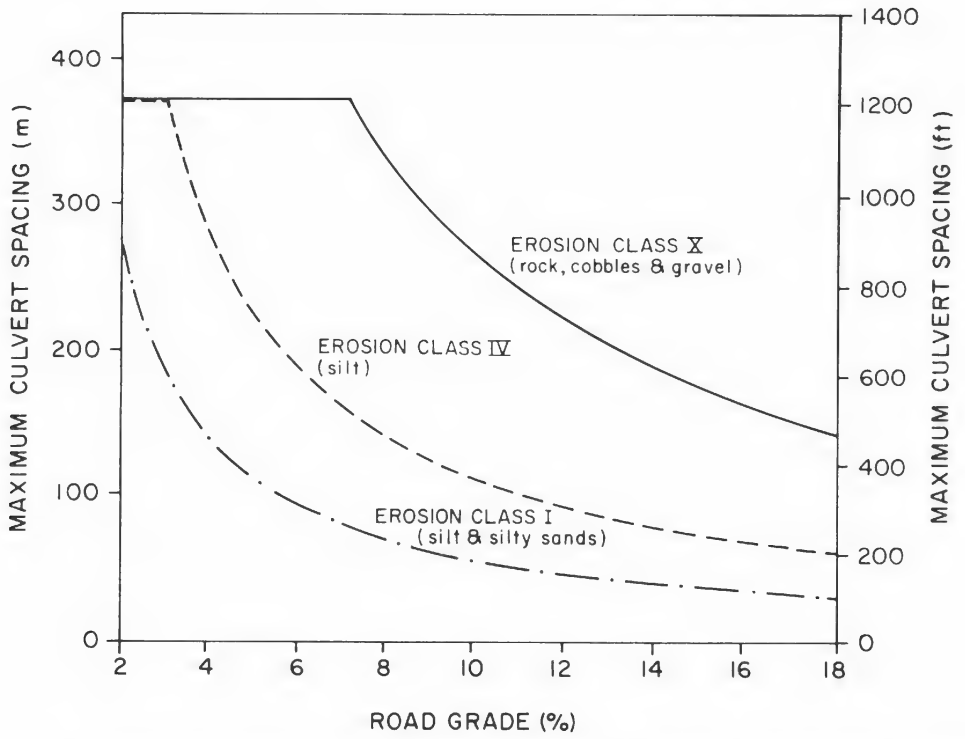

Figure 2. Sample guideline for culvert spacing (adapted from Arnold, 1957). The most erodable soils are in erosion class I; the least erodable, in erosion class X.

for non-independence in the data. However, adjacent DCR's were often separated by topographic ridges, the crest of a vertical curve, or stream crossing culverts (stream crossing culverts were excluded from this analysis). Thus the potential dependency may be relatively small. Furthermore, the basic design of DRC's is for independent operation. Dependence between adjacent DRC's will only occur if an up-grade culvert fails, and by-passes water and sediment down to the next DRC culvert.

During the summers of 1984 and 1985, DRC's were characterized by diameter and length, spacing, inlet condition, skew angle, slope, and outlet erosion. Outlet erosion was determined by visually projecting surface contours across any erosion below the pipe outlet and calculating the volume of eroded soil. Five hundred and fifteen DRC's were evaluated, although some variables could not be measured at all culverts.

Results and Discussion

The DRC's evaluated in this study were on 1- to 1.5-lane roads. Over 50 percent of the DRC's were near ridgetops, reflecting the practice of building roads near ridges to minimize direct impacts to riparian zones, reduce risk of mass failure from mid-slope roads, and provide access for harvesting systems that can remove felled timber efficiently and with minimal onsite impacts. Gravel road surfaces associated with these culverts averaged 4.1 ± 0.8 m (13.5 ± 2.6 ft.) wide (mean ± standard deviation); road subgrades averaged 6.6 ± 1.4 m (21.7 ± 4.6 ft.) wide. Fifty-five percent of the DRC's were made of corrugated steel; 31 percent, of corrugated steel with asphalt; 11 percent, of aluminum; and 3 percent, of concrete. Most (90%) had projecting entrances. Culvert lengths averaged 10.7 ± 2.6 m (35.1 ± 8.5 ft.); diameters and cross-sectional areas are given in Table 1.

TABLE 1. Dimensions of ditch relief culverts in the central Oregon Coast Range (n = 515).

Diameter (cm)	Cross-sectional area (m^2)	% of culverts
30.5 (12 in.)	0.07 (0.79 ft^2)	1
38.1 (15 in.)	0.11 (1.23 ft^2)	36
45.7 (18 in.)	0.16 (1.77 ft^2)	62
70.0 (24 in.)	0.29 (3.14 ft^2)	1

Culvert Spacing

Average number of DRC's per mile on U.S. Forest Service roads was 38 to 98 percent greater than for other ownerships (Table 2). Actual spacings in our study area exceeded Arnold's guidelines (Figure 2) by an average of 70 percent (Table 2). Ditch erosion generally was not a problem with the forest roads sampled, except where spacing distances were exceptionally large. Long ditchlines between DRC's, which were frequently found on state and private roads, diverted ditchwater into small streams at crossings, or onto slopes at switchbacks or topographic "saddles."

Inlet Condition

The relative importance of sediment plugging, pipe damage, cutbank sloughing, organic debris blockage, or combinations of these factors was evaluated by expressing existing cross-sectional area of the culvert inlet as a percent of original area (Figure 3). Average cross-sectional area for all DRC inlets was 81 percent of original; averages ranged from 73 percent for private lands to 85 percent for state lands.

Inlet areas had been reduced in 74 percent of the DRC's. Sediment deposition, occurring at 24 percent of the installations, was the main cause. Physical damage or denting, the second most frequent cause, occurred at 17 percent of the installations. Where sediment deposition or denting occurred separately, each reduced the cross-sectional area of DRC inlets to an average of approximately 80 percent of original area. Another 7 percent of the culverts were reduced by combined effects of sediment and denting; average cross-sectional area for these pipes was only 61 percent of the original. Thus, inlets of nearly half (48%) of the DRC's were reduced by sediment, denting, or both. Cutbank slumpage severe enough to affect entrance conditions was

TABLE 2. Ditch-relief culverts in the central Oregon Coast Range: owners, spacing, and outlet erosion volumes.

Owner	Sampled road sections n	Sampled road sections %	Ditch relief culverts n	Ditch relief culverts %	Culverts/km[a]	Relative Culvert spacing[b]	Outlet erosion volume (m^3)[a,c]
USDA Forest Service	52	52.5	326	63.3	5.1 [2.2]	1.3 [0.8]	0.6 [1.8]
USDI Bureau of Land Management	27	27.3	118	22.9	3.5 [1.2]	2.1 [1.7]	0.6 [1.8]
State	10	10.1	37	7.2	3.7 [1.7]	2.4 [1.7]	1.4 [2.8]
Private	10	10.1	34	6.6	2.6 [1.6]	2.7 [2.0]	1.3 [3.6]
Average	—	—	—	—	4.4 [2.1]	1.7 [1.3]	0.7 [2.1]
Total	99	100.0	515	—	—	—	—

[a]Mean [standard deviation]

[b]Mean [standard deviation] culvert spacing relative to Arnold's (1957) guidelines, i.e., observed spacing/Arnold's spacing. For example, a mean value of 1.7 indicates that the observed spacing was 70 percent greater than indicated by Arnold's guidelines.

[c]Two outlet erosion volumes (i.e., landslides comprising 841 and 127 m^3) were not utilized in calculating the "outlet erosion volume" mean and standard deviation (see text.)

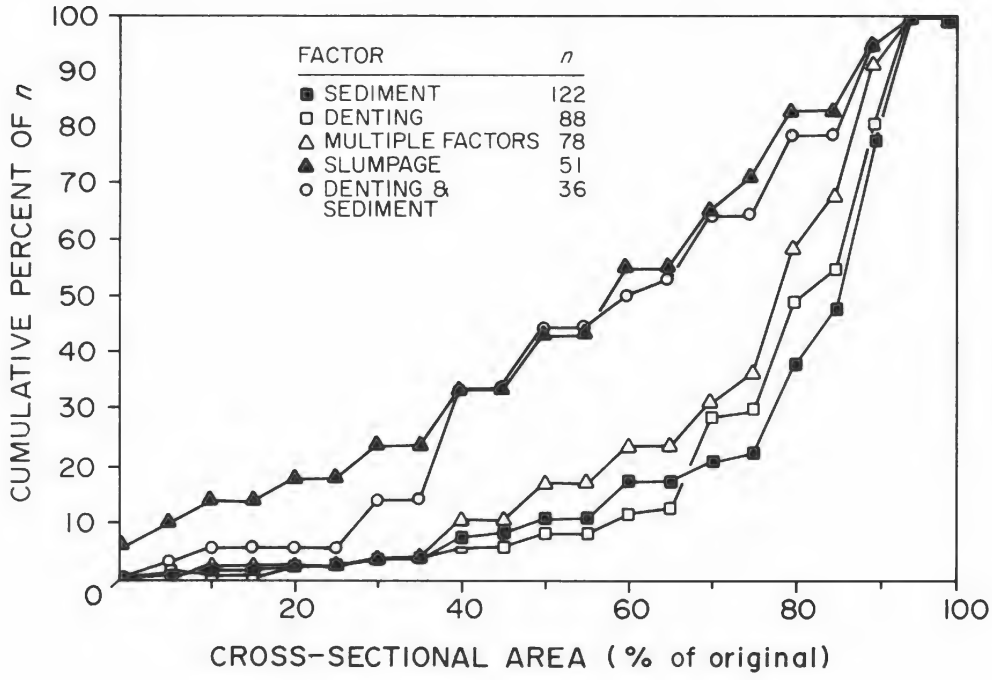

Figure 3. Factors affecting reduction in cross-sectional area of ditch-relief-culvert inlets.

relatively infrequent (10% of all DRC's) but reduced inlet cross-sectional area to an average of 56 percent of the original. Only 1 percent of the DRC's were plugged by organic debris. Multiple factors affected inlet cross-sectional area in another 15 percent; area of these inlets averaged 74 percent of original area.

The only aspects of inlet condition that might be influenced by between-culvert dependence is plugging of an inlet with sediment or organic debris. Since by-passing of water, sediment or organic debris from one pipe to the next would require nearly complete plugging of the first pipe, which was not found, dependence is unlikely and the evaluated inlet characteristics should provide a reasonable representation of inlet conditions for the population of DRC's in the central Oregon Coast Range.

Skew Angle

Garland (1983) suggested that ditch relief culverts be installed with approximately 30° of skew (Figure 1); skew angles in this study averaged 15° (Figure 4A). Greater skew angles should help pass water, sediment and debris through culvert inlets. As skew angle decreases, water flowing along the ditch and any transported material must turn more sharply to enter the pipe; as a result, water velocity is reduced and sediment, organic debris, or both may be deposited. However, reductions in cross-section area at DRC inlets by sediment and debris accumulation were not significantly correlated with skew angle ($P > 0.10$).

Culvert Slope

The slope of DRC's generally should be at least 3 percent to maintain high water velocity and prevent deposition of sediment (Rothwell 1978); over 90 percent of the DRC's met this criterion. Culverts also should be inclined 2 percent more than the road grade (Rothwell 1978); only 40 percent of the DRC's in this study satisfied this criterion. Average slope of DRC's was 6 percent (Figure 4B); average road slope was 7 percent. Sediment deposition at DRC inlets was less at

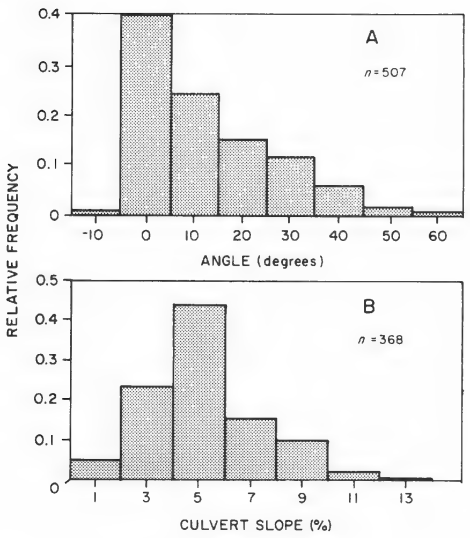

Figure 4. Distribution of (A) skew angles, and (B) slopes for ditch-relief culverts.

steeper pipe slopes. Unexpectedly, these steeper pipes also had a higher percentage of dented inlets and an increased occurrence of cutbank slumpage.

Outlet Condition

Outlet erosion volume (volume of soil removed by erosion of roadfill, hillslope, or both) was estimated at each culvert outlet; measurable outlet erosion was associated with 38 percent of the DRC's. In two cases, large landslides below the culvert outlets resulted in erosion volumes (841 and 127 m^3) that comprised 72 percent of the total outlet erosion for all culverts. Because landslides occur by a different mechanism than surface erosion by water evident for the remainder of the culverts, these two values were not included in this analysis. Landslides are an important problem associated with forest roads, but any analysis would require a much larger data set than the two slides we observed. Outlet erosion volumes of the remaining culverts (Table 2) averaged 0.73 m^3 (0.96 yd^3).

Outlet erosion volumes increased with increased spacing, averaging 3.4 m^3 (4.4 yd^3) per culvert where spacing exceeded Arnold's (1957) guidelines by more than 100 percent, but only 1.2 m^3 (1.6 yd^3) where spacing exceeded those guidelines by less than 100 percent. The observed spacing of culverts on U.S. Forest Service lands exceeded Arnold's guidelines by an average of 30 percent. In contrast, spacing distances on private lands averaged 170 percent greater than Arnold recommended (Table 2).

Fillslopes were rated qualitatively and placed into one of three categories: "stable," "eroding intermittently," and "eroding actively." Sixty percent of the fillslopes fell in the first class, 28 percent in the second, and 12 percent in the third. The proportion of culverts associated with intermittently and actively eroding roadfills increased as spacing, expressed as a percentage of Arnold's (1957) guidelines, increased (Figure 5).

Conclusions

A consistent procedure for DRC spacing on low-volume forest roads has not been used in the central Oregon Coast Range, and spacings typically exceed those identified by Arnold (1957). Widely spaced DRC's would tend to carry more water during major rainfall events, and the potential for erosion is increased, as indicated by greater erosion volumes associated with larger spacings. Where outlet erosion is significant, reducing DRC spacing should decrease outlet erosion. With continued outlet erosion, roadfills on steep slopes may ultimately be undermined and fail. Field observations indicated that ditch erosion was not a problem between most DRC's.

Large landslides were found below the culvert outlets for two of the 515 DRC's evaluated. Although some aspect of road drainage may have been associated with these slides, neither the physical evidence nor statistical inference from such a small sample size could be used to confirm this.

Our use of Arnold's (1957) spacing guidelines is not meant to imply that his spacings are necessarily the "standard" to be used for DRC spacing in western Oregon. We chose them as a basis for comparison because they have existed for 30 years and provide guidelines on a site-specific basis. To our knowledge they have not been systematically evaluated. Furthermore, the guidelines are based on several important variables that might logically be expected to affect DRC spacing, i.e., erosion classes based on soil characteristics, ditchline gradient, and precipitation intensity. The development of new or

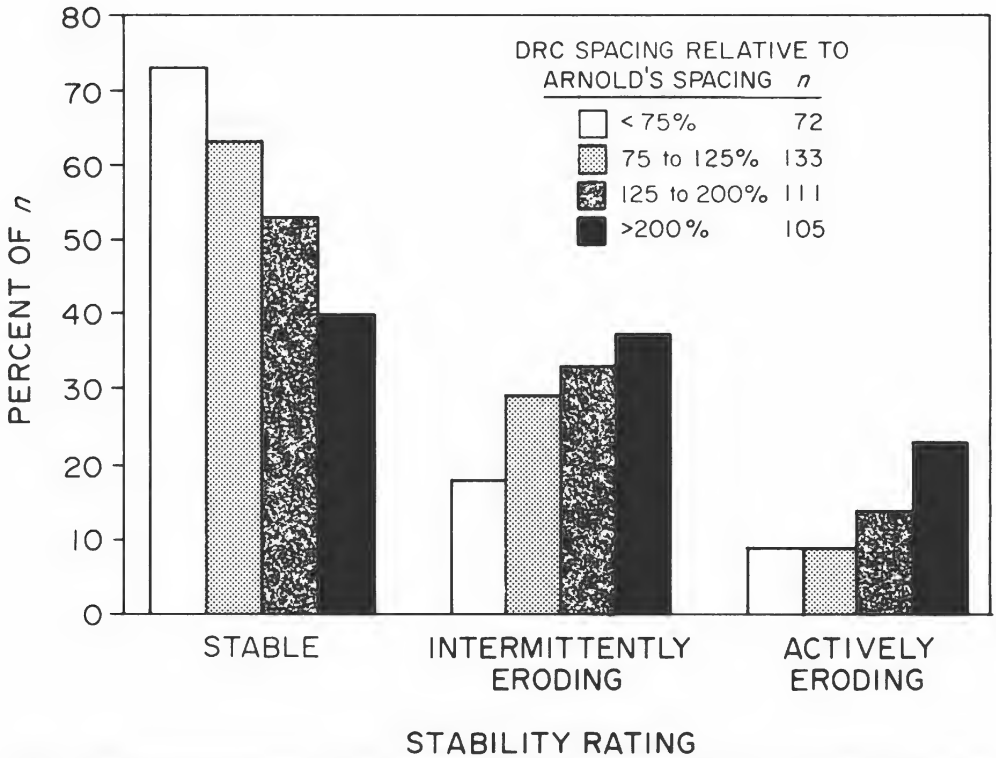

Figure 5. Stability rating of fill slopes of ditch-relief culverts (DRC), in comparison with Arnold's (1957) spacing guidelines.

revised spacing guidelines was beyond the scope of this study.

Little culvert plugging by organic debris was found which may indicate that existing maintenance programs are keeping inlets acceptably free of woody debris. Road maintenance (i.e., grading of road surfaces and cleaning ditches or inlets with equipment) and vehicle travel can damage inlets and reduce cross-sectional area. The relatively high percentage of inlets with reduced cross-sectional area indicates that improved maintenance procedures, quality control, or inlet design may be needed to prevent continued damage and denting. Whether this reduction is considered in original sizing and design of culverts is not known.

This study provides an initial evaluation of ditch-relief culverts within a relatively limited geographic area of coastal Oregon. Our ability to extrapolate these results or compare them with results from other areas and ownerships is limited. The scientific literature is noticeably deficient in research on road drainage structures in mountainous terrain. Given the thousands of miles of low-volume roads in Oregon alone, this regrettable lack of knowledge may severely limit the ability of forest landowners to manage transportation systems efficiently and to reduce storm-related road damage.

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Annual Diet of Bobcats in Oregon's Cascade Range

Abstract

Because little information exists on the role of the bobcat (*Felis rufus*) as a predator in coniferous forest ecosystems, this study was initiated to determine the annual diet of bobcats in the coniferous forest of Oregon's Cascade Range. Diet was determined from analysis of 494 scats. Dominant prey species identified were snowshoe hares (*Lepus americanus*), black-tailed deer (*Odocoileus hemionus*), and mountain beaver (*Aplodontia rufa*); remains of these species occurred in 30 percent, 22 percent, and 12 percent of scats examined, respectively. A variety of cricetid and sciurid rodents, birds, insectivores, and reptiles were also identified. The greatest diversity in the seasonal diet of bobcat occurred during spring, while the least diversity occurred during winter. Mean prey size taken by bobcats in the spring (426 g) was approximately half during winter (827 g). Diets of bobcats were most dissimilar between winter and spring. The variety of prey taken seasonally by bobcats and the wide range in prey size indicate the potential for competition with other predators. Knowledge of the seasonal variation in the bobcat diet should allow wildlife managers to more effectively manage both bobcats and their potential prey species.

Introduction

Little information is available concerning bobcat food habitats in coniferous forests of the Pacific Northwest. Several authors reported on small samples from the Coast Range of western Oregon (Schwartz and Mitchell 1945, Sweeney 1978, Witmer and deCalestra 1986); only Nussbaum and Maser (1975) reported bobcat diet in the Cascade Range. This paper reports on the annual and seasonal diet of bobcats from the central Cascade Range of western Oregon.

Study Area

This study was conducted in Oregon's Cascade Mountain Range, within the Willamette National Forest approximately 55 km east of Eugene, Lane County, Oregon (43°, 55' N; 122°, 30' W). Terrain was abruptly dissected by drainages of the North Fork of the Middle Fork Willamette River. Elevations range from about 500 m to 1,500 m. Climate was typical of the Western Cascade maritime area with mild, wet winters and warm, dry summers. Precipitation occurred about 160 days per year and averaged about 150 cm annually. Mean annual snowfall averaged about 163 cm; the latest date with 150 cm of snow usually occurred in late March (Lahey 1979). Annual temperature extremes ranged from −18 to 38°C.

Vegetation was typical of the Western Hemlock (*Tsuga heterophylla*) Zone as described by Franklin and Dyrness (1973). Logging, reforestation projects, and forest fires have resulted in a dominance of Douglas-fir (*Pseudotsuga menziesii*) with smaller, isolated stands of western red cedar (*Thuja plicata*). Grand fir (*Abies grandis*), Pacific silver fir (*Abies amabilis*), western yew (*Taxus brevifolia*), and western white pine (*Pinus monticola*) occurred commonly. Understories were dominated by creambrush oceanspray (*Holodiscus discolor*) on dry sites, Pacific rhododendron (*Rhododendron macrophyllum*) and Cascade hollygrape (*Berberis nervosa*) on intermediate sites, and sword fern (*Polystichum munitum*) and Oregon oxalis (*Oxalis oregana*) on mesic sites (Franklin and Dyrness 1973).

Methods

Scats were collected on the study area from 15 October 1982 through 30 June 1984. All roads on the 280 km² study area were cleared of scats prior to initiation of daily collections so that only fresh material was collected. Each scat was labeled and air dried prior to separation and identification of prey remains. Prey items in some of the scats were separated from other undigested residues as collected, but bones were separated from most scats using an 8 percent (2M) solution

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of NaOH to digest the associated conglomerate (Green *et al.* 1986). Samples of hair were removed from scats prior to NaOH digestion for comparison with hair keys (Mayer 1952, Stains 1958, Adorjan and Kolenosky 1969) to aid in prey species identifications. Bones in the scats were identified by comparison with skeletal materials in the vertebrate museum of the Department of Fisheries and Wildlife, Oregon State University.

Each scat was subjected to a three-part identification procedure. Each scat was identified to species in both the field and the laboratory based on color, texture, odor, and (in the field) associated tracks and scrapes. A portion of each scat was subjected to thin-layer chromatography for identification of bile acid residues present (Major *et al.* 1980, Johnson *et al.* 1981, Johnson *et al.* 1984). Chromatography was used to derive final identification where other characteristics were not definitive.

Similarity indices (SI) between seasonal diets were calculated according to Horn (1966); using the index, values could range between zero (no food items in common between seasons) and 1 (identical diets between seasons).

Mean prey size was calculated seasonally for all species identified from bobcat scats and weighted by frequency of occurrence. This calculation provided a slight over-estimate of mean prey size since several specimens of small prey of the same species in a single scat were recorded as one occurrence, as was a single specimen of larger size. Ungulate remains were excluded from these calculations since many may have been eaten as carrion. Weights of adult mammals were taken from Maser *et al.* (1981) and from weights recorded for museum specimens at Oregon State University. Mammal nomenclature follows Jones *et al.* (1982); plant nomenclature follows Garrison *et al.* (1976).

Results

Four hundred ninety-four bobcat scats were analyzed (Table 1). Snowshoe hares (*Lepus americanus*), black-tailed deer (*Odocoileus hemionus*), and mountain beaver (*Aplodontia rufa*) were the food items most commonly identified. Hares made up the largest portion of the diet throughout the year and occurred in > 33 percent of scats during fall and winter. Second in frequency of occurrence was black-tailed deer, occurring in 22 percent of scats examined (Table 1). Deer remains occurred in 27 percent of fall and 31 percent of winter scats, and were the most frequently identified prey item during December and January, when they occurred in 46 percent of bobcat scats. Black-tailed deer were the second most abundant prey in the bobcat diet during February, March, April, and May (Table 1). Remains of fawns were identified from a single bobcat scat collected in May, from 6 scats (8%) in June, 8 (18%) from July, and 1 (2%) from August. Fawns accounted for 11, 55, 6, and 17 percent of all deer remains identified from bobcat scats collected in May, June, July, and August, respectively. In July, black-tailed deer remains (fawns and adults) were the most frequently identified food item. Remains of calf elk (*Cervus elaphus*) were identified in four bobcat scats from June and July.

Mountain beaver were the third-ranking item in bobcat diets, and occurred in greatest frequency during spring (16%) and summer (17%) months. Cricetid rodents of 9 species (Table 1) occurred in 23 percent of the scats, varying from 9 percent in winter to 37 percent in spring. Six species of sciurid rodents (Table 1) comprised 17 percent of the bobcat diet. Squirrels were eaten by bobcats most frequently in the fall (28%) and least frequently in the summer (11%). Insectivores were found in 17 percent of bobcat scats during spring months, but did not occur in scats from other seasons (Table 1). The most frequently identified insectivore, the coast mole (*Scapanus orarius*), occurred in 13 (7%) spring scats.

Remains of birds occurred in 47 (10%) scats. Most were passerines, but only 1 slate-colored junco (*Junco hyemalis*) and 11 ruffed grouse (*Bonasa umbellus*) could be positively identified. Eggshell fragments occurred in 5 scats. Reptile remains occurred in 9 percent of spring scats. Like insectivores, reptiles occurred in the bobcat diet only during spring (Table 1).

Masticated green grass was found in 55 (11%) of the scats, and some scats consisted solely of grass. On two occasions, freshly passed scats that consisted solely of masticated grass and entwined tapeworms were found. Blackberries (*Rubus* sp.), huckleberries (*Vaccinium* sp.), Cascade hollygrape (*Berberis nervosa*), and manzanita (*Arctostaphylos* sp.) were identified in 33 (7%) scats. In each instance, fruit was associated with other, animal prey and may represent food of other

TABLE 1. Prey items identified from 494 bobcat scats from Oregon's Cascade Range. Values are number of occurrences; percent frequency of occurrence follows.

	Jan-Mar		Apr-Jun		July-Sep		Oct-Dec		Annual	
	(N = 112)		(N = 187)		(N = 105)		(N = 90)		(N = 494)	
Prey Item	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent
MAMMALS										
Odocoileus hemionus	35	31	30	16	20	19	24	27	109	22
Cervus elaphus	5	4	4	2	2	2	4	4	15	3
Spilogale gracilis	0	0	1	1	0	0	1	1	2	—
Canis latrans	0	0	2	1	0	0	0	0	2	—
Lepus americanus	43	38	48	26	29	28	30	33	150	30
Ochotona princeps	2	2	4	2	8	8	1	1	15	3
Aplodontia rufa	9	8	30	16	18	17	0	0	57	12
Thomomys mazama	1	1	10	5	10	10	2	2	23	5
Castor canadensis	1	1	0	0	0	0	0	0	1	—
Glaucomys sabrinus	5	4	1	1	1	1	10	11	17	3
Tamiasciurus douglasii	8	7	6	3	1	1	3	3	18	4
Tamias townsendii	2	2	11	6	5	5	7	8	25	5
Tamias amoenus	2	2	3	2	1	1	0	0	6	1
Spermophilus beecheyi	0	0	3	2	1	1	2	2	6	1
Spermophilus lateralis	0	0	2	1	1	1	1	1	4	1
Unknown Sciurid	1	1	1	1	2	2	2	2	6	1
Neotoma cinerea	3	3	5	3	1	1	2	2	11	2
Peromyscus maniculatus	2	2	13	7	4	4	3	3	22	4
Cleithrionomys californicus	2	2	6	3	2	2	1	1	11	2
Arborimus albipes	0	0	2	1	0	0	0	0	2	—
Zapus trinotatus	0	0	5	3	5	5	0	0	10	2
Ondatra zibethica	0	0	2	1	1	1	1	1	4	1
Microtus oregoni	0	0	13	7	1	1	1	1	15	3
Microtus richardsoni	0	0	4	2	1	1	2	2	7	1
Microtus longicaudus	1	1	4	2	1	1	0	0	6	1
Unknown cricetid	2	2	16	9	6	6	2	2	26	5
Scapanus orarius	0	0	13	7	0	0	0	0	13	3
Scapanus townsendii	0	0	2	1	0	0	0	0	2	—
Neurotrichus gibbsii	0	0	4	2	0	0	0	0	4	1
Sorex trowbridgii	0	0	6	3	0	0	0	0	6	1
Sorex vagrans	1	1	4	2	0	0	0	0	5	1
Sorex monticolus	0	0	1	1	0	0	0	0	1	—
Sorex sp.	0	0	1	1	0	0	0	0	1	—
Unknown Mammal	6	5	16	9	7	7	8	9	37	7
BIRDS										
Bonasa umbellus	1	1	3	2	3	3	4	4	11	2
Junco hyemalis	0	0	0	0	0	0	1	1	1	—
Unknown Passerine	7	6	9	5	10	10	4	4	30	6
Eggshell	0	0	4	2	1	1	0	0	5	1
REPTILES										
Sceloporus occidentalis	0	0	8	4	0	0	0	0	8	2
Eumeces skiltonianus	0	0	1	1	0	0	0	0	1	—
Diadophis punctatus	0	0	1	1	0	0	0	0	1	—
Thamnophis sp.	0	0	1	1	0	0	0	0	1	—
Unknown Snake	0	0	6	3	0	0	0	0	6	1
INSECTS	0	0	4	2	0	0	1	1	5	1
FRUIT	3	3	1	1	25	24	4	4	33	7

animals ingested by bobcats. Human refuse including plastic sandwich bags, cotton cloth, and paper was found in 5 scats.

Fall and winter diets were most similar (SI = 0.942), comprised primarily of snowshoe hares, black-tailed deer, and a variety of sciurid and cricetid rodents (Table 2). Bobcat diets changed in the spring. Spring diets included all prey eaten during fall and winter, along with increased frequency of mountain beaver, western pocket gophers (*Thomomys mazama*), microtines, cricetines, and birds. Insectivores and reptiles occurred in the spring diet only. The variety of prey identified in the bobcat diet increased from 17 during the winter to 35 during the spring (Table 3). Mean prey size during spring averaged 426 g (Table 3), about half that during winter (827 g). Winter and spring diets were the most dissimilar (SI = 0.759) of any seasonal comparison (Table 2). The second-greatest change in bobcat diet between successive seasons occurred between summer and fall (Table 2). Percentages of snowshoe hares, black-tailed deer, and sciurids in the bobcat diet increased from summer to fall, with decline in use of mountain beaver, mice, and birds. Despite the difference in seasonal diet indicated by a low SI value (0.779), the number of kinds of prey (21 in summer, 19 in fall) and mean prey size (529 g in summer and 539 g in fall) were nearly identical.

TABLE 2. Pair-wise diet similarity indices for bobcats in Oregon's Cascade Mountain Range.

Season	Winter	Spring	Summer	Fall
Spring	0.759	—	—	—
Summer	0.779	0.803	—	—
Fall	0.942	0.770	0.779	—
Annual	0.906	0.935	0.906	0.919

TABLE 3. Variety of prey and weighted mean size of prey identified from 494 bobcat scats collected from Oregon's Cascade Range.

	Season			
	Winter	Spring	Summer	Fall
Variety of Prey[a]	17	35	21	19
Weighted Mean Prey Size (g)[b]	827	426	529	539

[a]From Table 1.

[b]Ungulates excluded.

Discussion

Lagomorphs are important prey in bobcat diets throughout the United States (McCord and Cardoza 1982) as well as in eastern Oregon (Toweill 1982), several portions of the Coast Range (Schwartz and Mitchell 1945, Nussbaum and Maser 1975) and in the Cascade Range (Nussbaum and Maser 1975, this study). Mountain beaver dominated bobcat diets in some (typically low-elevation) portions of the Coast Range (Sweeney 1978, Witmer and deCalesta 1986).

The frequency of occurrence of black-tailed deer in the diet of bobcats in the Cascade Range was unexpected because of the size differential of the two species (approximately 6.0 kg vs. 68 kg). Many authors have attributed remains of deer found in bobcat food habit studies to scavenging (Hamilton and Hunter 1939, Rollings 1945, Pollack 1951, Erickson 1955, Progulske 1955, Gashwiler *et al.* 1961). In this study, remains of deer in bobcat scats occurred primarily during the fawning period and again during the winter, when alternate prey was probably least available. However, the high incidence of deer in the bobcat diet during periods when alternate prey availability was believed to be low leads to speculation that bobcats may prey on deer, as has been suggested by others (Marston 1942, Westfall 1956, McCord 1974, Beasom and Moore 1977, Fritts and Sealander 1978). The ability of bobcats to kill adult as well as fawn deer has been well documented (see McCord and Cardoza 1982). Major changes in bobcat diet between warm and cold seasons (winter/spring SI = 0.759; summer/fall SI = 0.779), were noted in this study. These changes were associated with a steady seasonal decline in prey diversity and increase in weighted mean prey size from spring through winter (Table 3).

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Soil Moisture Classification in Northwestern Washington

Abstract

Since little documentation is available for classifying soil moisture in northwestern Washington, the objective of this study was to classify the soil moisture regime of the Whatcom soil, the soil of largest extent in the area. The moisture content of this soil was determined by comparing the weight of water in each field sample collected weekly or biweekly with its respective oven-dried weight. The research was conducted from 1981 to 1985 during the critical summer months when the soils dry from evapotranspiration and when precipitation reaches its annual minimum. In Whatcom soils, as well as for other upland soils in western Washington, the deciding factor for classifying the soil moisture regime according to *Soil Taxonomy* is the amount of time the soil moisture control section is dry in all parts to a tension more than 1.5 M Pa. A comparison of the soil moisture data for 1981 to 1985 with the corresponding five years of precipitation and extrapolating the relationship to the total 35 years of climatic record indicates that Whatcom soils do not dry to tensions >1.5 M Pa for sufficient time to classify the soil moisture regime as xeric, the current classification. The appropriate classification appears to be udic. These findings may have an impact on studies on plant moisture uptake and summer irrigation in western Washington.

Introduction

Soil moisture has been classified from a climatological (Thornthwaite 1948) as well as a soils perspective (Soil Survey Staff 1975). In western Washington, soil moisture has eluded classification due to the variable summer precipitation. Although the climate appears to typify a Mediterranean type, in which summer precipitation is dramatically lower than the winter maximum, it actually qualifies as a Marine west-coast climate based on the ratio of July precipitation to evapotranspiration (Strahler and Strahler 1983).

Soil moisture classification schemes are usually based on some interrelationship between soils and plants, although Thomas *et al.* (1973) found that soils in western Oregon could not be grouped clearly into xeric and udic moisture regimes using such a system. *Soil Taxonomy,* in particular, uses the seasonal distribution of precipitation, the amount of time and depth the soil is saturated, and the amount of time the soil moisture control section is dry to a tension less than 1.5 M Pa (Soil Survey Staff 1975). The intent in defining the soil moisture control section is to facilitate estimating soil moisture regimes from climatic data.

Many of the soils in the mesic temperature regime above the flood plain in western Washington are currently classified in the xeric moisture regime (Soil Conservation Service 1984). These soils become moist from a combination of capillary movement from the high water table, lateral flow, and rainfall. There is little, if any, documentation showing the quantitative relationship between climate and changes in soil moisture in northwestern Washington and, thus, to establish if there is sufficient soil water to keep the moisture control section below a tension of 1.5 M Pa and prevent the consecutive days of dryness for a xeric moisture regime. This study was undertaken to produce some base data for soils in the northern part of this region, to estimate the soil moisture regime from climatic data, and to test the taxonomic placement of the soils in the xeric moisture regime.

Methods

The soils examined are the established Whatcom series, which are fine-loamy, mixed, mesic Aqualfic Haplorthods, based on the presence of silt pellets and cracked coatings in the Bs horizon and argillans in the 2Bt horizon (Table 1). They formed in glacialmarine drift with an admixture of loess and volcanic ash (Goldin 1988). The closest climatic record to the study site is taken at the Bellingham station, which is located 13 km southeast at an elevation of 30 m (Table 2). No measurements were taken on-site, but other nearby stations, such as the Clearbrook station 28 km northeast, show similar summer rainfall patterns.

The moisture contents at 1.5 M Pa and 33 k Pa were measured by the USDA National Soil Survey Laboratory using standard procedures (Soil Conservation Service 1972) (sample number

TABLE 1. Typical pedon of the Whatcom series, on a 2 percent south-facing slope in pasture at 50 m elevation.

Ap—0 to 23 cm; dark brown (10YR 3/3) silt loam, brown (10YR 5/3) dry; weak fine granular structure; soft, very friable, nonsticky, nonplastic, weakly smeary; many fine and common fine roots; many very fine irregular pores; 5 percent pebbles and 2 percent concretions; NaF pH 10.5; medium acid (pH 6.0); abrupt smooth boundary.

Bs1—23 to 33 cm; dark brown (7.5YR 4/4) silt loam, light brown (7.5YR 6/4) dry; weak fine subangular blocky structure; soft, very friable, nonsticky, nonplastic, weakly smeary; many very fine roots; many very fine irregular pores; 5 percent pebbles and 1 percent concretions; NaF pH 11.5; medium acid (pH 6.0); clear smooth boundary.

Bs2—33 to 41 cm; dark brown (7.5YR 3/4) silt loam, light brown (7.5YR 6/4) dry; weak fine subangular blocky structure; soft, very friable, nonsticky, nonplastic, weakly smeary; many very fine roots; many very fine irregular pores; 5 percent pebbles and 1 percent concretions; NaF pH 12.0; medium acid (pH 6.0); abrupt smooth boundary.

2Btl—41 to 51 cm; light olive brown (2.5Y 5/4) loam, pale yellow (2.5Y 7/4) dry; many medium prominent mottles of dark yellowish brown (10YR 4/4), yellowish brown (10YR 5/4) dry; medium thick platy struture; slightly hard, friable, slightly sticky, slightly plastic; common very fine roots; many very fine irregular pores; few, thin patchy clay films on faces of peds; 5 percent pebbles; NaF pH 9.8; medium acid (pH 6.0); clear smooth boundary.

2Bt2—51 to 66 cm: light olive brown (2.5Y 5/4) loam, light gray (2.5Y 7/2) dry; many coarse prominent mottles of yellowish brown (10YR 5/6), reddish yellow (7.5YR 6/6) dry; moderate thick platy structure; slightly hard, friable, nonsticky, nonplastic; few very fine roots; many very fine irregular pores; few, thin patchy clay films on faces of peds; 10 percent pebbles; NaF pH 10.0; medium acid (pH 6.0); abrupt smooth boundary.

2C1—66 to 89 cm; light olive gray (5Y 6/2) loam, white (5Y 8/2) dry; many medium prominent mottles of light olive brown (2.5Y 5/6) moist and dry; moderate thick platy structure; very hard, firm, slightly sticky, slightly plastic; common very fine irregular pores; 5 percent pebbles; NaF pH 9.4; neutral (pH 6.6); clear smooth boundary.

2C2—89 to 150 cm; dark gray (5Y 4/1) loam, light gray (5Y 7/1) dry; moderate coarse blocky structure; extremely hard, very firm, slightly sticky, slightly plastic; very few very fine irregular pores; 5 percent pebbles; NaF pH 9.6; mildly alkaline (pH 7.6); slightly effervescent.

TABLE 2. Total precipitation record for the months of June through September for Bellingham, Washington, 1951-1985. Values in mm.

Year	June	July	August	September	4 Month Sum
1951	5.6	2.0	9.9	37.3	54.8
1952	50.5	14.5	8.1	22.3	95.4
1953	51.2	20.5	22.6	52.7	147.0
1954	50.2	37.8	58.8	30.4	177.2
1955	49.2	44.9	6.8	29.1	130.0
1956	115.4	3.6	34.5	84.2	237.7
1957	41.8	50.0	17.5	23.3	132.6
1958	19.5	0.0	7.4	48.4	75.3
1959	34.7	12.9	33.7	108.0	189.3
1960	31.7	0.0	68.5	53.8	154.0
1961	23.1	34.0	30.4	41.1	128.6
1962	37.5	9.6	119.2	60.1	226.4
1963	32.0	52.7	10.9	26.1	121.7
1964	48.9	60.9	44.9	102.2	256.9
1965	13.2	5.8	92.6	34.5	146.1
1966	26.6	66.7	23.1	53.0	169.4
1967	30.2	19.5	8.4	52.5	110.6
1968	71.5	28.1	80.1	65.9	245.6
1969	38.0	13.4	15.2	141.5	208.1
1970	34.2	41.6	4.3	63.7	141.6
1971	85.5	44.6	7.4	105.8	243.3
1972	59.1	63.9	36.3	53.0	212.3
1973	36.3	9.6	17.8	35.5	99.2
1974	38.3	50.0	3.0	12.7	104.0
1975	30.2	45.6	92.6	12.2	180.6
1976	53.0	20.5	67.5	27.6	168.6
1977	18.3	38.3	52.5	46.4	155.5
1978	53.3	15.5	68.0	110.3	247.1
1979	58.8	29.7	40.6	48.4	177.5
1980	84.4	40.1	23.8	72.5	220.8
1981	104.7	61.9	14.7	56.0	237.3
1982	31.4	83.9	26.6	32.5	174.4
1983	44.9	66.4	28.7	104.5	244.5
1984	64.1	3.0	50.2	82.4	199.7
1985	54.3	2.5	2.8	53.5	113.1
mean	46.3	31.3	35.1	56.7	169.3
s	24.0	23.3	29.8	31.2	55.1
mean (81-85)	59.9	43.5	24.6	65.8	193.8
s (81-85)	27.8	38.1	17.7	28.0	53.4

S81WA-073-008). The change in soil moisture was examined for five consecutive years during May through October. Several moisture analyses made between October and May showed the soils to remain at or near field capacity. The gravimetric moisture content was determined at approximately one to three week intervals during the sampling period (Figures 1 and 2). Gravimetric moisture analysis is the standard for soil moisture (Schmugge *et al.* 1980, McKim *et al.* 1980) and

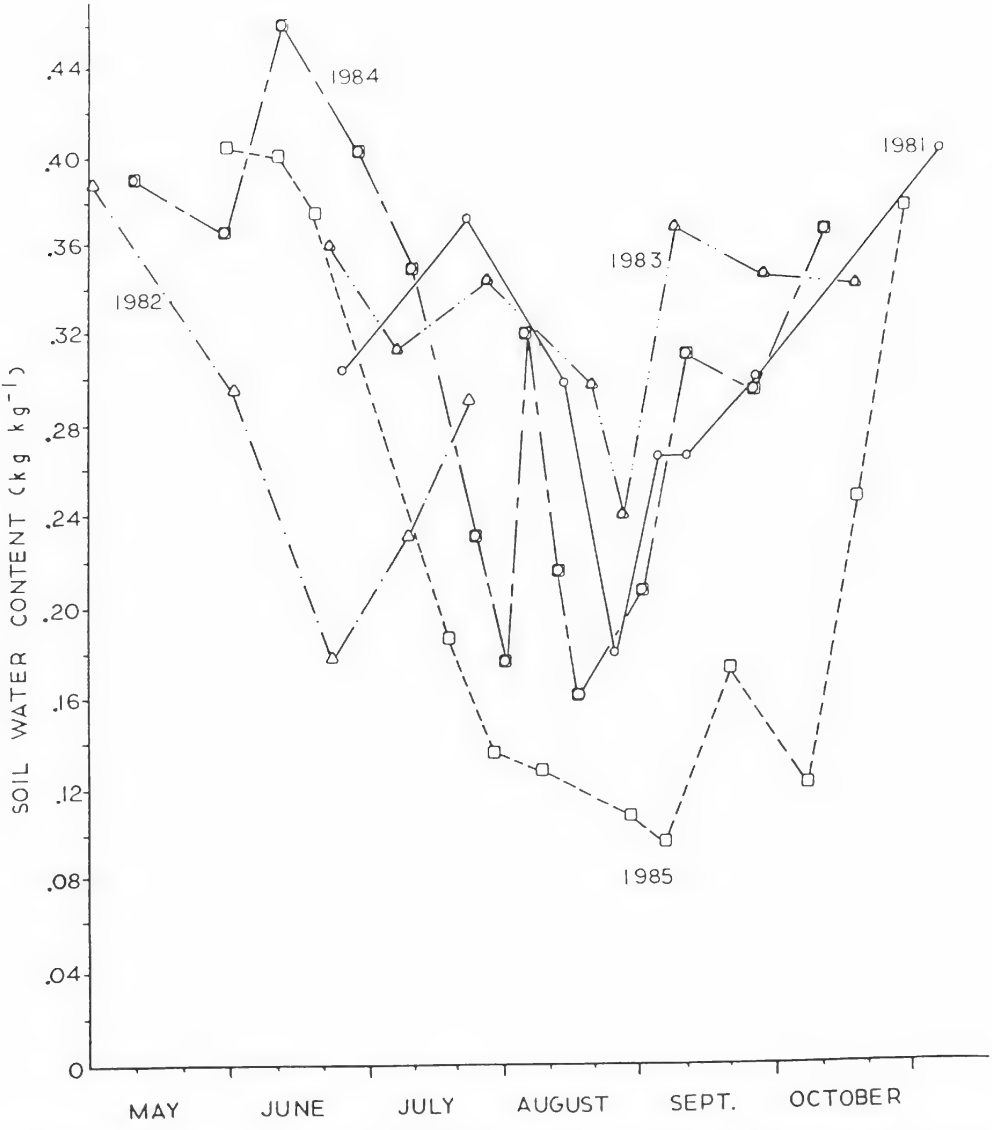

Figure 1. Changes in soil moisture content in the Whatcom series at 0.1 to 0.15 m during May through October 1981-1985.

was used for that reason. Sample acquisition is fast and inexpensive and covers the pressure potential range from 0 to more than 1.5 M Pa.

Samples were taken from 10 small pits adjacent to the type location of the series. This site is in pasture and is not irrigated. Moisture analyses, at several locations in an adjacent woodland site, were made starting in 1982, since it was assumed the soil under forest would be dryer due to greater transpiration. However, the moisture levels were almost identical to those at the type locations in pasture so only occasional

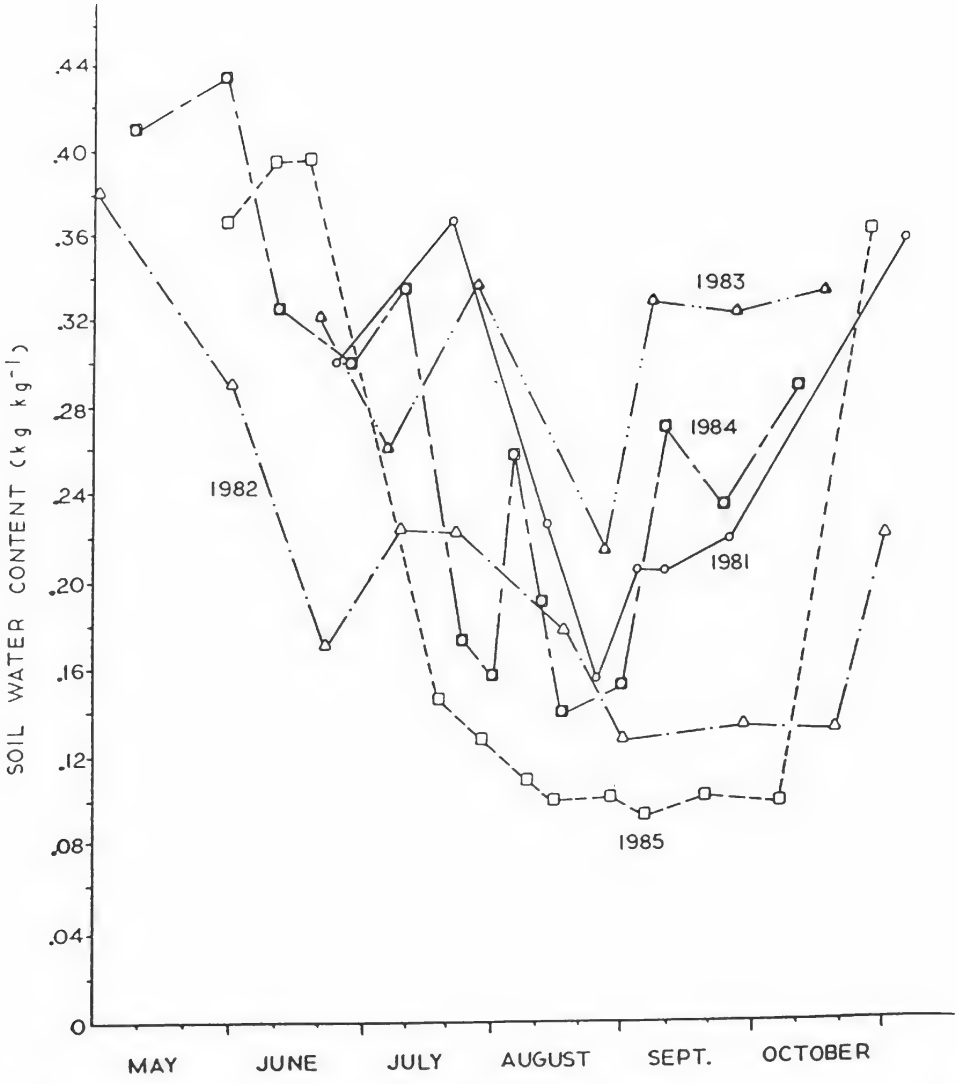

Figure 2. Changes in soil moisture content in the Whatcom series at 0.3 to 0.35 m during May through October 1981-1985.

measurements were taken thereafter at the woodland site to confirm the correlation.

The boundaries of the soil moisture control section are defined as the depths in a soil which will be moistened by 24-hour rainfall events of 25 and 75 mm, respectively (Soil Survey Staff 1975). Samples were taken at depths of 0.1 to 0.15 and 0.3 to 0.35 m, which is the approximate boundary of the soil moisture control section for soils of these textures (Soil Survey Staff 1975). The upper sample fits within the soil moisture control section of 0.06 to 0.19 m for the Whatcom soil as defined by the methods of Zobeck and Daugherty (1982).

Soils such as the Whatcom soils with dense substrata are recharged from the surface and dry out gradually as moisture is utilized during the growing season. Lateral water movement is unlikely in unsaturated conditions.

Results

If the soils are to meet the definition of the xeric moisture regime as defined in *Soil Taxonomy*, they must satisfy the three criteria: 1) they must be dry in all parts of the soil moisture control section to a tension more than 1.5 M Pa, 2) they must be dry for 45 or more consecutive days, and 3) they must be dry within the four months that follow the summer solstice in six or more years out of ten. In western Washington, if they dry for less time, they would be placed in a udic regime since they remain saturated in winter. The other mositure regimes (aquic, aridic, and ustic) are inappropriate due to the oxidizing conditions and high soil chroma, the amount of soil moisture, and the distribution of precipitation in the Whatcom soils, respectively.

The soils at the beginning of the sampling period each May were at approximately field capacity based on sampling of the profiles at this time and comparing the moisture content to the laboratory determined values at 33 kPa (Table 3). The moisture content decreased steadily until late August except for increases immediately after summer rainfall events, but reached the moisture value at 1.5 M Pa tension only in 1985, when a record summer drought occurred. The minimum water contents for the 1981-1985 sampling period were 15.6 kg kg^{-1}, 12.8 kg kg^{-1}, 21.4 kg kg^{-1}, 14.0 kg kg^{-1}, and 9.3 kg kg^{-1}. The only run of consecutive dry days during the five years was <10 days in the upper horizon in 1985.

The 1.5 M Pa values determined by the National Soil Survey Laboratory were based on rewetted airdry samples (Dennis Nettleton, National Soil Survey Laboratory, personal communication). The amount of moisture held at this tension is significantly affected by allophane (Rousseaux and Warkentin 1976), which is common in Spodosols (Farmer 1982, Ross 1980). Whatcom soils contain about 2 percent allophane (Nettleton *et al.* 1985). Drying soils with allophane decreases their surface area, promotes shrinkage, and causes a decrease in water retention, CEC, and clay content as determined by mechanical analysis (Warkentin and Maeda 1974). Soils from Oregon that have high allophane content have been shown to hold 50 to 100 percent more water at 1.5 M Pa when analyzed moist than when rewetted from airdry (John Baham, Oregon State University, personal communication).

TABLE 3. Moisture values for the Whatcom series.

Depth (cm)	33 kPa (kg kg^{-1})	1.5 M Pa (kg kg^{-1})
0-23	60.9	9.5
23-33	31.6	8.5
33-41	31.8	8.9
41-51	20.8	6.3
51-66	21.9	9.3
66-89	26.7	9.3
89-150	15.9	12.6

In order to determine the long-term soil moisture regime, we must develop a relationship between soil moisture and climate based on the five sampling years in comparison to the 35 years on record. Although June and July 1981; July 1982; July and September 1983; June, August, and September 1984; and June 1985 were more than 10 percent above their respective monthly averages, the months of August 1981; June, August, and September 1982; August 1983; July 1984; and July and August 1985 were more than 10 percent below their respective monthly averages. Examining the records, we see that the mean for the five summers as well as the means of each of the five individual months (with three exceptions: July 1984, July and August 1985) are within one standard deviation of the respective means for the record period (Table 2).

The years 1981, 1983, and 1984 had above average precipitation and 1982 and 1985 were below average. In 1985 the soils dried to tensions >1.5 M Pa for <10 days, even though this was the longest rainless period on record. Based on Figure 1, the minimum moisture contents in which Whatcom soils are dry for 45 consecutive days in 1981, 1983, 1984, and 1985 in the 0.1 to 0.15 m layer are 30.6 kg kg^{-1}, 34.3 kg kg^{-1}, and 14.0 kg kg^{-1}, respectively. These are considerably higher than the 1.5 M Pa values of Table 3. The

1982 data are missing. The lowest value for the Whatcom soil for 1981-1985 was 9.3 kg kg^{-1} in the lower horizon and 9.6 kg kg^{-1} in the upper horizon in early September, 1985. If field moist samples were analyzed for 1.5 M Pa water content, the values would probably be higher, but even 50 percent higher would be insufficient to cause the soils to classify in the xeric moisture regime.

Whether by ground water recharge, higher field capacity than the lab-determined value due to layering, the average 40 mm per month summer precipitation, or the soil's ability to resist drying due to self-mulching, the moisture content remains above the 1.5 M Pa level or rises above it frequently enough to break any 45 day run. Two month stretches of less than 50 mm have occurred in 12 of the 35 years of record (Table 2), and in all but three of these 12 bimonthly periods, the previous month had more than a 10 percent overrun to build up the soil moisture storage before the dry period.

Since 1930, approximately half of each of the months June, July, August, and September received more than 110 percent of the respective average precipitation. Two-thirds of any two consecutive month period had more than 10 percent overruns and more than 80 percent of three consecutive months a 10 percent overrun.

Determining how likely a soil is to dry out for 45 consecutive days in 6 or more years out of 10 is difficult to determine without long-term analysis. However, upon examining the 35 years of precipitation records and comparing this with the precipitation during the study period, none had less July and August precipitation than 1985, and only 4 years (or 11%) had drier four-month totals; only in these years could the soils have dried to the 1.5 M Pa tension for 45 consecutive days, certainly less than the required minimum of 6 or more years out of 10, specified for the xeric moisture regime.

Conclusions

Based on a comparison of precipitation records for 1981-1985 with previous years, the climate during the study period was within one standard deviation of precipitation means. If the assumption is valid that the corresponding soil moisture conditions are also typical, we are led to the conclusion that the Whatcom series does not exceed 1.5 M Pa tensions for the required 45 consecutive day period for 6 or more years out of 10. The soil moisture reaches these tensions only under unusual circumstances, which occur much less than 60 percent of the time. Thus, these soils appear to stay moist long enough (i.e., they don't dry out long enough) to be classified in a udic, rather than a xeric moisture regime.

Using Whatcom soils to represent other soils in western Washington which have been classified in the xeric moisture regime, it appears that if soils in this area were intended to be "xeric" to differentiate them taxonomically from udic soils in the Midwest, the definition of the xeric moisture regime needs to be changed to include them. This could be done by reducing the number of consecutive dry days or lowering the tension at which they are considered dry.

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Downstream Migration of Stained Kokanee Fry in the Flathead River System, Montana

Abstract

The purpose of this study was to determine the migration patterns of newly-emerged kokanee fry in the Flathead River, an upstream drainage of the Columbia River system. Knowledge of the timing of arrival of migrating fry to Flathead Lake from natal streams is vital in monitoring reproductive success of the kokanee population. In a series of three experiments, we stained kokanee fry in 1:30,000 solutions of Bismarck brown (a vital stain) and followed their movements downstream through the river system. Fry migrated from dusk to dawn and traveled at the same speed or slightly faster than the current in moderate velocity sections of the river, and up to twice as fast as the flow rate in the low velocity river section. Fry migrated 100 km from McDonald Creek through the Flathead River system to Flathead Lake in as little as 20 hours. Fry stained for 50 minutes in the 1:30,000 Bismarck brown solution showed distinct dye retention for one week. Stain was still visible after two weeks on fry examined on a white background. Mortality was low for control groups of stained and unstained fry. Our experiments indicated that most migrating kokanee fry in the Flathead River system moved actively to take advantage of currents. Actively migrating kokanee fry probably experience higher survival because of reduced exposure to riverine predators. Kokanee fry behavior during migration in the Flathead River system is similar to that of sockeye salmon fry in coastal streams.

Introduction

Kokanee (*Oncorhynchus nerka*) mature in three to five years in Flathead Lake, Montana, then migrate upstream in the fall to spawn in the Flathead River system. Fry emerge in the spring and migrate up to 120 km downstream to the lake. The pattern and rates of fry migration had not been understood clearly because previous work focused on unmarked fry of uncertain origin (Fraley and Graham 1982).

We marked three groups of kokanee fry with a vital stain (Bismarck brown Y) and followed their movements downstream for 100 km from McDonald Creek to Flathead Lake. We conducted these experiments to determine timing of fry recruitment to Flathead Lake and to determine if fry migration was passive or active. This information is needed for our studies of seasonal growth and distribution of young-of-the-year kokanee in the lake. Other workers have monitored migration of (anadromous) sockeye salmon fry (e.g., Hartman *et al.* 1962) but few have followed the movements of marked fish. Stober and Hamalainen (1980) followed movements of stained sockeye fry in the Cedar River, Washington.

In this paper, we report on the timing and rate of movement of kokanee fry migrating from McDonald Creek downstream through various sections of the Flathead River to Flathead Lake. We also report on dye retention and mortality of fry stained in a 1:30,000 solution of Bismarck brown Y.

Study Area

The Flathead River system in northwest Montana is a headwater drainage of the Clark Fork of the Columbia River (Figure 1). Flathead Lake is the largest natural lake west of the Rocky Mountains. It is oligomesotrophic and has a surface area of 476 km^2 and a mean depth of 32.5 m (Potter 1978). Kerr Dam on the outlet regulates the level of the lake within 3 m of the surface.

The Flathead River enters the north end of the lake. The lower 35 km of the inlet river is influenced by Kerr Dam, and is slough-like with a silt bottom. From there upstream for 55 km to its forks, the river has a moderate gradient and gravel-rubble substrate. The North, Middle and South forks drain areas of nearly equal size from portions of the Great Bear and Bob Marshall Wilderness Areas, Glacier National Park, and the Flathead National Forest.

Kokanee rear to maturity in Flathead Lake and return to natal areas to spawn, usually at the end of their fourth growing season (Fraley and Graham 1982). Kokanee spawn in many habitats, including springs, streams, large river channels, and along the shorelines of lakes. Presently, the major spawning area for kokanee in the Flathead

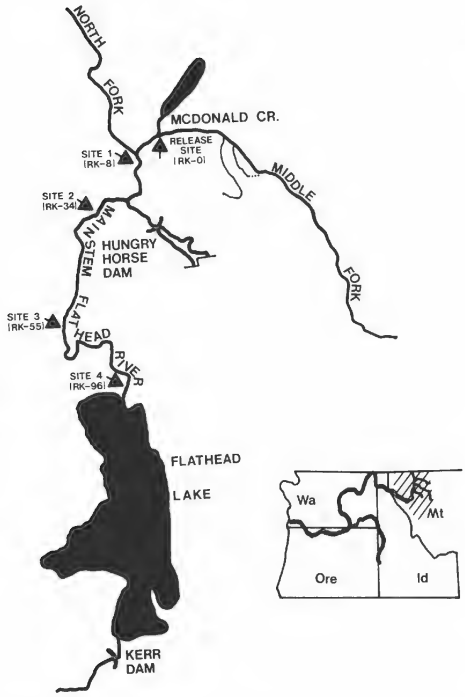

Figure 1. Locations of the kokanee fry release and capture sites in the Flathead River drainage, and location of the drainage within the Columbia River system (inset).

system is the 4-km outlet of McDonald Lake, in the Middle Fork drainage within Glacier National Park. Kokanee spawn in the South Fork of the Flathead River from Hungry Horse Dam downstream 8 km to the confluence with the main Flathead River, and in portions of the main stem Flathead River. However, the spawning populations at both locations have been reduced by the operation of Hungry Horse Dam and other factors (Fraley and Decker-Hess 1987). Few kokanee spawn in the North Fork drainage.

The substrate of McDonald Creek is mainly gravel and water temperature is moderated by McDonald Lake. From 1979 to 1986, kokanee spawning escapement into the creek ranged from 21,500 to 120,000 fish, accounting for 75 percent of the spawning run from Flathead Lake (Fraley and Decker-Hess 1987). Estimates of fry emigration from the creek from 1982 to 1986 ranged from 6.6 to 13.1 million (Beattie and Clancey 1987).

Methods

We conducted three experiments on kokanee fry migrating downstream during the spring in 1983 and 1984. Fry were captured with drift nets suspended overnight in McDonald Creek from the Quarter Circle Bridge below the outlet of McDonald Lake at the confluence of the Middle Fork Flathead River. Nets were located at intervals across the stream channel at surface, subsurface and bottom depths (Fraley and McMullin 1983). Captured fry were assumed to be outmigrating from the creek. Fry were counted volumetrically and emersed for 50 minutes in an aerated live tank with solutions of Bismarck brown Y vital stain at a concentration of 1:30,000 (i.e., 1 g dye/30 l water). Powdered dye was mixed with water in a 19 liter bucket (0.5 g dye/15 l water) then filtered through cotton cloth into the live car to remove dye residues which could have caused fry mortality (Fraley and McMullin 1983). Ward and VerHoeven (1963), and Stober and Hamalainen (1980) also stained salmon fry with Bismarck brown Y at a concentration of 1:30,000; they reported fry mortality of less than one percent and dye was retained for 7 to 13 days. Mundie and Traber (1983) used a dye concentration of 1:46,000 and reported almost no fry mortality and dye retention for five days.

After staining, fry were held in a mesh live car in the stream for one hour and allowed to recover before they were released. Our observations indicated that released fry distributed themselves along the bottom of the streambed. We captured no fry until dusk in drift nets maintained near the capture site. Therefore, we assumed that released fry remained near the capture site until dusk. Our observations indicated that fry frequented the streambed gravels during the day. Control groups of 50 stained and 50 unstained fry were held in mesh bags in the stream near the capture site throughout the course of each experiment and checked periodically for mortality and dye retention.

We sampled migrating fry with drift nets suspended from bridges located 8, 34, 55 and 96 km downstream from the release site (Figure 1, Sites 1, 2, 3, and 4). Drift nets consisted of a metal frame (0.5 m^2) with a tapered, trailing net bag

1.8 m long (3.2 mm mesh size). In areas of reduced velocity, the end of the bag was closed and fry were captured in the cod end. At faster velocities, a holding box was attached to the net to protect captured fry (Figure 2).

Drift nets (3 to 10 per site) were checked during the night at one to two-hour intervals and the number of stained and unstained fry were noted. Nets were left in place during the day and checked again at dusk. We operated each netting station until all stained fry had passed. During these experiments, nets were set in areas of high current velocity to capture as many fry as possible. Previous experiments (Fraley and Graham 1982) showed that migrating fry prefer areas of the water column with maximum velocity.

Flow rates in the Flathead River were calculated between sites 1 and 2, and sites 2 and 3, by timing releases of water from Hungry Horse Dam past each site. This was accomplished at flow levels similar to those experienced during the fry experiments. The rate of flow between sites 3 and 4 was calculated by measurements of water velocities at 0.5 m depth in channel transects spaced at 5 km intervals. Maximum velocities at each of the eight transects were averaged to arrive at an assumed flow rate for the 40 km section.

Results

We recaptured 807 (1.2%) of the 65,687 outmigrating kokanee fry stained and released in McDonald Creek during the three experiments. Stained fry migrated at night in loose aggregations through the Flathead River system, generally taking 1 to 4 hours to pass by each netting station. No stained fry were captured during the day. A similar percentage of total fry captured at each of the first three sites was stained. Most stained fry migrated as fast or slightly faster than the river current past sites 1, 2 and 3.

Movements of stained fry in the slower-flowing river section between sites 3 and 4 were more variable. Most fry traveled nearly twice the flow rate; however, some fry swam more slowly, taking up to five nights to reach site 4. Movement rates of fry varied among the three experiments, as indicated below.

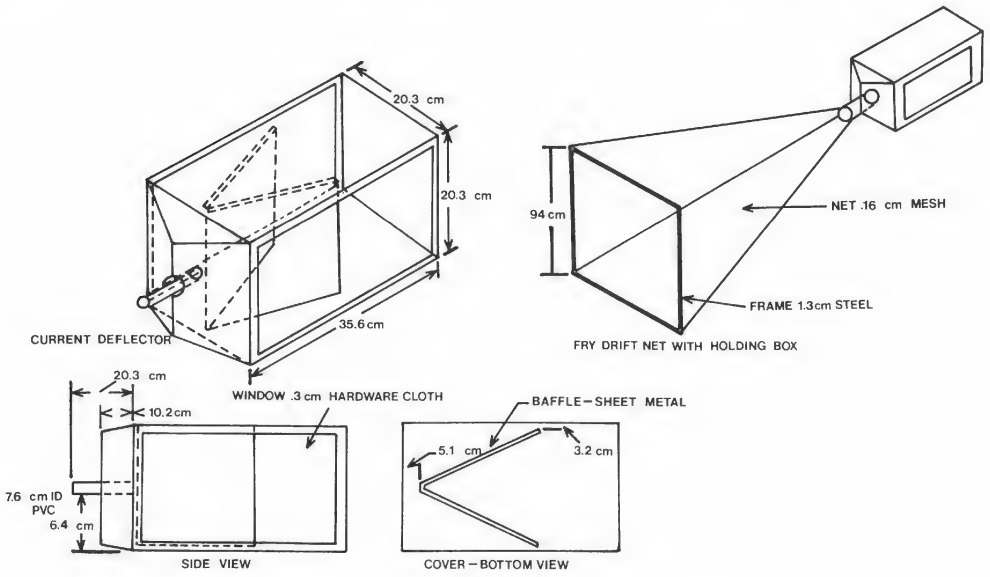

Figure 2. Fry holding box and drift net. Box is 1/2-inch plywood with 1/8-inch hardware cloth windows painted to reduce mesh size. Hinged top is 1/2-inch plywood; baffle and deflector are sheet metal.

Experiment 1

On 3 May 1983, 10,664 kokanee fry captured overnight in McDonald Creek in drift nets were dyed and released the next morning. We assumed that fry left the creek beginning at dusk or 2000 hours, based on lack of daytime captures in drift nets maintained at the release site. Past studies of nocturnal movements of fry in the creek support this contention (Fraley and Graham 1982). At 0130 hours (5.5 hours after dusk), stained fry had moved 8 km downstream to site 1 (Figure 3). Of 371 fry captured at site 1, 31 (8.5%), were stained. Only four stained fry were captured during the next 60 hours of sampling at Site 1. Fry reached site 2, 34 km downstream from McDonald Creek, at 0600 hours. We collected 164 fry during the night, and 18 (11%) were stained. We assumed that fry remained in the gravel along the margins of the Flathead River during the day as we had observed in McDonald Creek.

By 0030 hours the following night (5 May), the fry had moved 55 km downstream to site 3. We captured 52 fry during the night, and five (9.6%) were stained. We monitored site 4, just above Flathead Lake, for 10 days after the fry passed site 3; however, none of the 671 captured fry were stained.

Experiment 2

On 28 March 1984 we captured, stained and released 14,500 kokanee fry in McDonald Creek. By 2300 hours, stained fry had reached site 1 (Figure 3). Numbers of stained fry captured at site 1 peaked at 2400 hours. Of the 1,888 fry captured at site 1, 376 (20%) were stained.

Stained fry began to arrive at site 2 by 0500 hours the following morning (29 March) and continued passing the site until dawn. The fry apparently stopped moving during the day, as none were captured in the nets during daylight hours. At 2100 hours that evening, we again began to capture stained fry in the nets; they continued passing site 2 until 2400 hours. Of the 453 fry captured at site 2, 57 (13%) were stained.

Stained fry reached site 3 by 0200 hours that same night, and continued passing until 0500 hours. Of 539 fry captured at site 3, 78 (14%) were stained. We continued to monitor site 4 for eight additional days, but no more stained fry were captured.

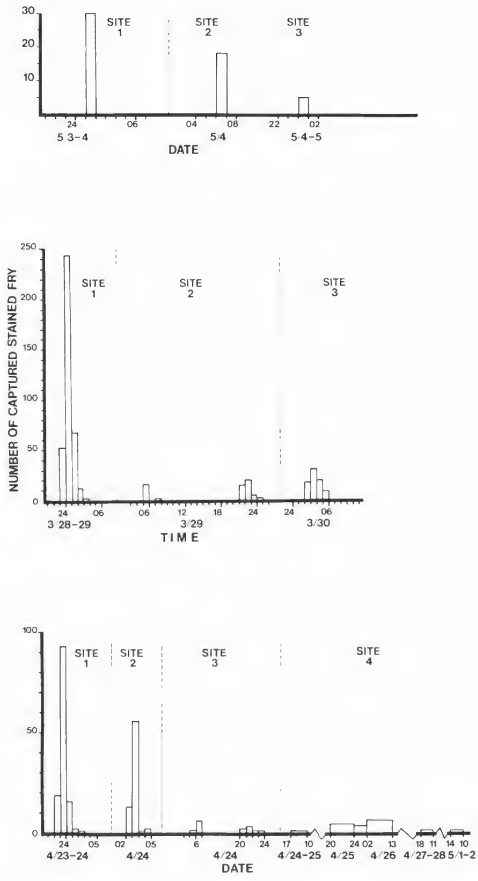

Figure 3. Number of stained fry captured and diel timing of migration during experiments 1 (top graph), 2 (middle graph) and 3 (bottom graph).

Experiment 3

On 23 April 1984 we captured, stained and released 40,523 fry in McDonald Creek. We maintained drift nets at the release site from 1200 hours that day. Large numbers of stained fry first appeared in nets set between 1900 and 2100 hours, confirming that fry began emigrating at dusk (approximately 2000 hours).

By 2200 hours, stained fry reached site 1 (Figure 3). Fry continued passing this point until 0200 hours (24 April). Of the 751 fry captured, 131 (17%) were stained.

Stained fry reached site 2 by 0230 hours, and continued passing until 0500 hours. Of 376 fry captured, 72 (20%) were stained. Stained fry reached site 3 by 0500 hours the same morning, after nine hours of travel time. Stained fry apparently stopped moving during the daylght hours, but resumed their migration past site 3 at 2100 hours the next evening. They were captured at this site until 2400 hours. Of the 123 fry captured, 14 (11%) were stained.

By 1000 hours the next morning (25 April), the first stained fry reached site 4, 96 km below the release point. We did not monitor the site hourly, so the fry arrived sometime between dusk and 1000 hours. Stained fry continued past site 4 that evening (Figure 3). From 2 to 4 percent of the captured fry passing this site were stained. Nets were operated at this site until 1 May. Of the 1,789 fry captured during the entire period, 20 (1.1%) were stained.

Fry Movement versus Current Flow

Most fry migrated downstream at nearly the same rate or faster than the calculated average flow rate during experiments 1 and 3 (Table 1). During experiment 1, flows in the Middle Fork and in the main stem Flathead River averaged 108 and 466 m^3/sec, respectively. Flows averaged 110 and 325 m^3/sec in the same streams during experiment 3. Fry moved nearly twice as fast as the river current between sites 3 and 4 (based on information from experiment 3). We assumed that similar current velocities existed under similar discharges during these experiments.

Stained fry moved downstream more slowly during experiment 2 (2.9 and 4.2 km/h between sites 1 and 2, and 2 and 3, respectively). Flows in the Middle Fork (26 m^3/sec) and in the Flathead River (108 m^3/sec) were much lower, and estimates of flow rates were not available.

Fry Mortality and Dye Retention

Similar mortality was observed in control groups of 50 stained and 50 unstained fry held in mesh bags in McDonald Creek during experiment 1. Mortality was 10 percent in the stained group and eight percent in the unstained group after eight days. In experiment 2, 50 dyed fry and 50 undyed fry were held for five days without mortality. The dye marking was distinct at the end of the holding period.

Fry stained for 50 minutes in a 1:30,000 solution of Bismarck brown Y stain showed distinct dye retention for one week. After two weeks, the stain was still visible on 90 percent of the fry when examined on a white background. Fin and mouth areas retained stain for up to 20 days.

Discussion

Kokanee fry emigrated from McDonald Creek in a loose aggregation beginning at dusk. Fry moved only at night, resting (or stopping) in gravel areas along the stream margin during the day. Our drift nets captured no stained fry during daylight hours. Previous studies of kokanee fry movements in the Flathead River system (Fraley and Graham 1982) also indicated nocturnal migration of fry. In an earlier diel experiment (Fraley and Graham 1982), the majority of fry emigrated from McDonald Creek between midnight and 0300 hours. Fry emigration began one-half hour after sunset (2030 hours) and continued until sunrise (0530 hours). Brannon (1972), Stober and Hamalainen (1980) and Nelson (1965) reported sockeye fry emigration occurred during a similar time period. Nelson (1965), however, found that although emigration always occurred at night, the exact hours of peak emigration varied widely throughout the emigration period, as well as from year to year.

Kokanee fry moved as fast or faster than the river current downstream from the North Fork. This indicated that they actively maintained position in the current, probably swimming through eddies and back currents. Many fry migrated up to twice the rate of current flow through the slow-moving section between sites 3 and 4. Fry were more dispersed at site 4 (one stained fry was captured two nights and one five nights after peak migration), indicating a larger variation in migration rates of individual fry where there is less current to transport them. Hartman *et al.* (1962) also found that sockeye fry migrated downstream faster than the water velocity. Kokanee fry migrated at a slower rate during periods of lower flows (experiment 2). We do not have an estimate of flow rate at the low discharges during experiment 2.

Our experiments indicated that some kokanee fry stage or congregate for varying periods in the Flathead River (between sites 3 and 4), possibly to rest or feed before entering the lake. Relatively few stained fry were captured at site 4 (3 km

TABLE 1. Current flows and movement rates of stained fry for each river section during experiments number 1 and number 3. Flow was not measured during experiment number 2.

	Distance (km)	Gradient (m/km)	Current flow rate (km/h)	Mean Movement Rate of Stained Fry (km/h)	
River Section				*Experiment 1*	*Experiment 3*
Site 1 to site 2	26	0.75	5.8	5.8	6.5
Site 2 to site 3	21	1.05	6.0	6.5	6.8
Site 3 to site 4	41	0.17	2.1	No Data	3.5

upstream from Flathead Lake) within 10 days of their release from McDonald Creek during experiment 3. No stained fry were captured at site 4 during experiments 1 and 2. Other factors which could have caused fewer stained fry in our samples at site 4 could be sampling inefficiency, fry mortality, or dispersal of fry.

Kokanee fry derive the energy required for migration from stored reserves and by feeding on early instars of aquatic insects. Approximately 10 percent of the fry emigrating from McDonald Creek had not yet absorbed their yolk sac. Migrating fry in the Flathead River system feed mostly on chironomids (Fraley and McMullin 1983).

Because many fry spend little or no residence time in the stream during migration, mortality caused by riverine predators is probably minimized. Stober and Hamalainen (1980) reported most stained sockeye fry in the Cedar River, Washington, emigrated from one to three days after they emerged from the gravel. The large size of some of the fry collected in McDonald Creek indicated that they had resided (for at least two weeks) in the creek before we captured them at the stream mouth. Spring areas in the Flathead system produce larger fry which, based on their size, remained up to one month before emigrating (Fraley and McMullin 1983). Variations in pre-departure residence times of fry in spawning areas, and variation in fry migration rates may have been important in the survival of kokanee in the system. Fry arriving in Flathead Lake at different times and at different sizes could take advantage of variations in abundance of zooplankton food.

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First Comprehensive Botanical Survey of the Columbia Plateau, Washington: The Sandberg and Leiberg Expedition of 1893

Abstract

In 1893 two field agents of the U.S. Department of Agriculture, John H. Sandberg and John B. Leiberg, made the first comprehensive botanical survey of the Columbia Plateau. Leiberg's never-published report of their expedition provides a general account of the distribution of much of the region's flora and its early agriculture. In addition, he identified the comparatively few native species that were becoming more prominent through disturbance (e.g., *Deschampsia danthonioides, Descurainia richardsonii,* and *Festuca microstachys*) and members of the enlarging alien flora (e.g., *Amaranthus retroflexus, Artemisia vulgaris, Bromus mollis, Bromus secalinus, Erodium cicutarium,* and *Verbascum thapsus*). His narrative provides a heretofore unavailable view of the region's flora just before the massive transformation of the steppe through the introduction of aggressive aliens, including *Bromus tectorum, Salsola kali,* and *Sisymbrium altissimum.*

Introduction

The natural grasslands or steppe in the Pacific Northwest have been drastically altered since European settlement: the frequency of fire, the magnitude of erosion, the cycling of minerals, the composition and productivity of the biota have all been changed irrevocably. The steppe in Washington exemplifies these changes (Daubenmire 1970, Rickard *et al.* 1977, Busacca *et al.* 1985, Mack 1986). Although this region was once dismissed as the "Great Columbia Desert," a land rush was sparked by the discovery in the late 1870's that much of these grasslands was eminently suitable for growing winter wheat. By 1890 almost 25,000 km^2 was in private ownership as farms or pasturage (Meinig 1968). These grasslands display low resiliency to disturbance (Mack and Thompson 1982, Harris *et al.* 1987), and the introduction of wheat agriculture, livestock and alien plants transformed the region by 1920 into arable fields and rangelands dominated by alien species such as *Bromus tectorum, Poa pratensis,* and *Salsola kali*[1] (Mack 1986).

This level of destruction is particularly unfortunate because the record of the natural vegetation compiled before 1940 is almost entirely anecdotal. Each plant collector beginning with the Lewis and Clark expedition of 1805-1806 included notes on vegetation along with his herbarium specimens (Thwaites 1905). But these early explorers seldom mentioned the region's vegetation and physical environments except in reference to their own hardships. For example, in 1841 Brackenridge trekked along the northern rim of the Columbia Plateau (McKelvey 1955). Neither his notes nor those of Geyer (1846) are little beyond a diary of the plants seen each day. Resident plant collectors such as Suksdorf (1892) compiled much of the regional flora but provided little ecological information. No detailed commentary was prepared of unplowed grasslands until Griffiths (1902) and Cotton (1904) examined the Okanogan Valley and northern half of the Columbia Basin, respectively. The first ecological investigation that included quantification was not conducted until 1913 and was restricted to Whitman County (Weaver 1917). Shantz's commentary on the regional vegetation was based on a rapid trip that was largely restricted to railways (Shantz and Zon 1924). Comprehensive study of the steppe vegetation in Washington did not begin until 1937, culminating in Daubenmire (1970).

Given this paucity of information from the 19th century, the recent discovery of a heretofore unknown manuscript based on a botanical survey on the Columbia Plateau in 1893 provides the earliest known account of the original distribution of much of the steppe flora. Unlike other accounts written before 1940, many of the botanical observations in the manuscript can be verified because the field notes and most of the catalogued specimens to which it refers have been preserved. The report was apparently

[1]Nomenclature follows Hitchcock *et al.* (1955-69).

written by John B. Leiberg based on the expedition he and J. H. Sandberg undertook as U.S.D.A. field agents in the spring and summer of 1893. The timing of their trip was fortuitous because they would have seen the Columbia Plateau in transition from native steppe to agro-ecosystems. As early as 1893, it was becoming widely recognized that the region's original bunchgrasses (particularly *Agropyron spicatum* and *Festuca idahoensis*) were severely over-grazed and were being rapidly destroyed (e.g., An Illustrated History of Whitman County 1901, Shear 1901). The Union Pacific Railroad had already ended the open range policy on its land in a futile attempt to reduce the damage by itinerant herders (Brodie 1898), and feeble and often misguided attempts were being launched to find substitute forage grasses (Mack 1981).

Despite the potential scientific value of an account of the 1893 expedition, it was not published. Much of the manuscript had been completed by early 1896 because Leiberg then informed C.V. Piper, a botanist at what is now Washington State University that, "I think the report of the Washington collection of '93 will appear next spring, possibly also that of the Oregon trip of '94 and the one in Idaho of '95, but am not sure." (papers of C. V. Piper, in Manuscripts, Archives, Special Collections, Washington State University). In the annual Report of the Botanist (U.S.D.A.) for 1897, Leiberg's report is noted as forthcoming, "...but its publication has been postponed in order to permit the incorporation of the data by now being secured by local botanists in remote portions of the area." Further delay probably resulted from Leiberg's transfer to the U. S. Geological Survey. Leiberg continued his botanical work in the Pacific Northwest (Leiberg 1900), but neither the report for the 1893 trip in Washington nor for his 1894 trip to eastern Oregon was completed before his death in 1911. The appearance of Piper's more comprehensive *Flora of Washington* in 1906 probably signalled the end of any need for further U.S.D.A. botanical surveys. Fortunately, the 122 page typed manuscript of the 1893 trip was preserved in the archives of the now defunct Division of Botany in the National Archives and Records Service.

My paper is based on this unpublished manuscript (Sandberg and Leiberg n.d.), the "Catalogue of plants collected by J. H. Sandberg and J. B. Leiberg in Washington during 1893" (Anonymous n.d.), Leiberg's list of plants collected on this trip (unpublished notes in the Archives of the University of Oregon), and the examination of 613 of their 837 vascular plant specimens that are deposited at Washington State University (WS) and the National Museum of Natural History (US). (They also made 44 collections of bryophytes and hepatics that I have not examined.) I will refer throughout this paper to Leiberg's report, thereby acknowledging his authorship of the manuscript.

Leiberg's Report of the 1893 Trip

"Acting under orders from the Hon. Secretary of Agriculture, J. Sterling Morton and the chief of the Botanical Division, Frederick V. Coville to make a collection of the flora of the Plains of the Columbia, to determine its east and west limits and to make observations on the climate, pasture, and agricultural areas of the region, and later in the season to ascend the eastern slopes of the Cascades to the summit of some of the higher elevations, we proceeded to Spokane, Washington, this city having been designated as the outfitting and starting point."

Upon leaving Spokane, Sandberg and Leiberg's first camp was established on May 15 on Hangman Creek south of the city; while based at this site they collected in northern Whitman County and southern Lincoln County. The rest of the trek proceeded in a generally westward direction: at Coal Creek (Camp 4), along Crab Creek (Camp 5, 6, & 7), to Wilson Creek (Camp 8), and arriving at Egbert Spring (near Ephrata) on June 30. They camped on the Columbia River near Rock Island, and then followed the Columbia to its confluence with the Wenatchee River. The rest of the survey was conducted along the Wenatchee River or its tributaries until they camped at the summit of Stevens Pass on 9 August. They stayed up to two weeks at each campsite and made daily collecting trips (Figure 1). At the end of August Leiberg recrossed the Columbia Plateau to Spokane along a more northerly route so as to ensure that no taxa were overlooked. By Leiberg's account they travelled 413 km from Spokane to the summit of Stevens Pass in the Cascade Range in about four months. Including the side trips and daily forays, he estimated that the expedition travelled a total of 2000 km.

Figure 1. The westward trek of Sandberg and Leiberg's expedition across the Columbia Plateau in 1893 generally followed the roadway of the Great Northern Railroad. The circled numbers indicate Sandberg and Leiberg's designation of their campsites as well as the campsites' locations and the chronology in which the camps were established. Roman numerals refer to their four major botanical districts; the Columbia River is the boundary between Districts II and III.

Compared to earlier collectors Sandberg and Leiberg were more mobile because their wagons could follow the newly-completed roadway of the Great Northern Railway in eastern Washington. Nevertheless, the trek was not easy. In a letter to C. V. Piper, Leiberg described plant collecting in the region as a slow and arduous process because of the rough terrain and the necessity of carrying supplies to deal with any emergency (papers of C. V. Piper, in Manuscripts, Archives,

Special Collections, Washington State University). Having Sandberg in nominal charge of the venture probably did not help. In 1893 Sandberg was described by a colleague at the University of Minnesota as, "... actually the most disputory botanist I ever had any thing to do with" (E. P. Sheldon letter to C. V. Piper, 1893, in Manuscripts, Archives, Special Collections, Washington State University). Sandberg also seems to have been careless in his note taking. Leiberg reported to Piper that Sandberg's report of 1892 (Holzinger 1895) erred by as much as 240 km in the location of specimens (papers of C. V. Piper, in Manuscripts, Archives, Special Collections, Washington State University).

Despite these difficulties the expedition accomplished its first goal of collecting the flora of the Plains of the Columbia. Even though other botanists had collected in the region, these collections from 1893 yielded at least 20 holotypes or isotypes. Leiberg described several of these new forms, including *Crepis barbigera* Leiberg ex Coville and *Delphinium viridescens* Leiberg. Several taxa were eventually named after Leiberg (e.g., *Erigeron leibergii* Piper, *Astragalus leibergii* Jones). Other taxa for which Sandberg and Leiberg's collections provided type specimens include *Antennaria tomentella* E. Nels. [*A. alpina* (L.) Gaertn.[1]], *Arenaria congesta* var. *prolifera* Maquire, *Carex nebrascensis* var. *ultriformis* Bailey [*Carex nebrascensis* Dewey[1]], *Carex neurophora* Mackenzie, *Crepis rostrata* Coville [*C. modocensis* ssp. *rostrata* (Coville) Babc. & Stebb.[1]], *Distichlis dentata* Rydberg [*D. stricta* var. *dentata* (Rydb.) C. L. Hitchc.[1]], *Erigeron poliospermus* var. *cereus* Cronq., *Hymenopappus columbianus* Rydberg [*Hymenopappus filifolius* Hook. var. *filifolius*[1]], *Lomatium suksdorfii* var. *thompsonii* Math. [*L. thompsonii* (Mathias) *Cronq.*[1]], *Mertensia brachycalyx* Piper [*M. paniculata* (Ait.) G. Don[1]], *Oreocarya spiculifera* Piper [*Cryptantha interrupta* (Greene) Parp.[1]], *Poa brachyglossa* Piper [*P. juncifolia* Scribn.[1]], *Saxifraga plantaginea* Small [*S. integrifolia* vars. *columbiana* and *leptopetala* (Piper) C. L. Hitchc.[1]] and *Viola verbascula* Greene [*V. adunca* Sm. in Rees[1]].

The Natural Vegetation of the Steppe

Sandberg and Leiberg were taxonomists, and their geographic divisions of the Columbia Basin were based on floristic, rather than vegetational, changes they saw as they travelled. Nevertheless, their delineation of four floristic "districts" adjacent to or within the Columbia Basin reveals the general distribution and composition of the natural communities they traversed. Proceeding westward from Spokane, their District I (Figure 1) was a 16-35 km wide belt of open forest, corresponding to the *Pinus ponderosa/Festuca idahoensis* zone (Daubenmire and Daubenmire 1968).

They included in District II much of the treeless plain in a 135 to 170 km swath across the northern half of the Columbia Plateau to the Columbia River. This large area encompassed three vegetation zones dominated by shrubby species of *Artemisia:* the *Artemisia tripartita/Festuca idahoensis,* the *Artemisia tridentata/F. idahoensis,* and the much larger *Artemisia tridentata/Agropyron spicatum* zone (Daubenmire 1970). District III delineated the vegetation from the Columbia River on the Douglas-Chelan County border to continuous forest about 30 km further west; a combination of the *A. tridentata/A. spicatum* zone and stands dominated by *Pinus ponderosa* (Daubenmire and Daubenmire 1968) (Figure 2). A fourth district included the mesophytic forests on the east side of the Cascade Range to its summit at Stevens Pass.

District I

The forest-steppe boundary in eastern Washington still retains the major features that Sandberg and Leiberg saw: open stands of *Pinus ponderosa* with understory dominants of either xerophytic grasses on zonal soils or mesic shrubs along the stream courses. They found that *Abies grandis* and *Pseudotsuga menziesii* were common associates along with *Betula occidentalis, Populus trichocarpa, Populus tremuloides* and *Salix lasiandra* var. *caudata.* Shrubs in these communities, especially near the stream edge, included *Ribes aureum, Salix* spp., *Sambucus cerulea,* and *Symphoricarpos albus. Crataegus douglasii* was also present, but Leiberg did not mention the extensive *Crataegus* thickets that Daubenmire (1968) reports occupying the stream courses further south in Whitman County. Perhaps wild fires set by the settlers had already eliminated these stands by 1893. Leiberg viewed the understory in these stands as a mixture of montane species at their western limits (*Arnica cordifolia, Ranunculus uncinatus, Smilacina stellata*) and steppe species more prevalent to the west

(e.g., *Eriogonum compositum, Eriogonum niveum, Polemonium pectinatum*). Sandberg and Leiberg found alkaline ponds invariably fringed by *Hesperochiron pumilus;* it was sometimes so abundant that in flower it appeared "...to whiten the ground as with a fall of snow." In contrast, Hitchcock *et al.* (1959) state that *H. pumilus* seldom if ever occurs on alkaline soil.

District II

This floristic unit included the bulk of the Columbia Plateau and contained communities on zonal soils dominated by *Purshia tridentata* and *Artemisia tridentata* with xerophytic grasses in the understory. Leiberg found these two shrubs "immensely abundant, especially in the middle and western portions of this section." Other arid shrubs included *Artemisia cana, Artemisia frigida* and *Artemisia rigida. Chrysothamnus viscidiflorus* was confined to the middle and western portions of the district, while *Sarcobatus vermiculatus* occurred around the margin of alkaline ponds. Grasses were clearly the co-dominants in all these communities. Aside from stating that *Agropyron spicatum* was the most prominent grass in this district, Leiberg gave no indication of the role of other grasses. Grasses he simply listed as occurring within District II include *Aristida longiseta, Bromus secalinus, Deschampsia danthonioides, Festuca microstachys, Festuca ovina, Koeleria cristata, Oryzopsis hymenoides, Poa sandbergii, Sitanion hystrix* and *Stipa comata.*

Leiberg also listed a diverse herbaceous understory in the upland communities on the northern Columbia Plateau. Prominent or frequently encountered species were *Antennaria dimorpha, Antennaria stenophylla, Astragalus collinus, Crepis atrabarba* var. *atrabarba, Crepis occidentalis, Erigeron filifolius, Eriogonum thymoides, Eriophyllum lanatum, Lagophylla ramosissima* and *Leptodactylon pungens. Balsamorhiza sagittata* is replaced by *B. careyana.* Many other species are listed but without any information on their abundance or distribution in the district.

Rhus glabra was common on the rocky slopes of the Columbia River in Douglas County as well as along the Spokane River. These records suggest that stands with *R. glabra* were once more extensive than reported by Daubenmire (1970). *Abies grandis, Pinus ponderosa* and *Pseudotsuga menziesii* were rare and confined to the bottom of coulees, talus slopes, and pond margins. *Juniperus occidentalis* was confined to the shoreline on the east bank of the Columbia River. These stream communities also contained many shrubs, including *Ribes aureum, Rosa woodsii,* and *Salix scouleriana. Alnus incana, Crataegus douglasii* and *Cornus stolonifera* were present only in the eastern portion of the district.

Sites with high salt content in valley bottoms supported a unique flora that could tolerate these alkaline and often water-logged soils. *Heliotropium curassavicum,* a borage, was widely distributed among these sites. Other species found were *Atriplex argentea, Distichlis stricta, Eurotia lanata, Iva axillaris, Myosurus minimus, Scirpus americanus, Scirpus nevadensis,* and *Spergularia marina.* Although Daubenmire (1970) recognized several associations on alkaline soils (e.g., *Elymus cinereus/Distichlis stricta; Sarcobatus vermiculatus/Distichlis stricta*), Leiberg made no distinction between the communities the expedition saw on these azonal soils.

Sandberg and Leiberg encountered sand dunes at three locations. One dune set at the southern end of Moses Lake was approximately 50 km south of the expedition's main route. For this site and the other dune sets they visited Leiberg merely listed the flora without commenting on relative abundance or distribution. The flora at the Moses Lake dunes included *Agropyron dasystachyum, Arenaria franklinii, Oenothera pallida, Orobanche fasciculata, Oryzopsis hymenoides, Phacelia glandulifera, Psoralea lanceolata, Rumex venosus* and *Coldenia nuttallii.* The species lists Sandberg and Leiberg compiled largely agree with the results of a reconnaissance Daubenmire (1970) made on a similar dune set in southern Franklin County.

Despite detailed floristic lists, Leiberg apparently did not detect the sharp E-W boundaries among communities that Daubenmire (1970) recognized. For example, in moving from their second to third campsite he apparently failed to notice a major change in the vegetation from the mesic sites supporting the *Symphoricarpos albus/Festuca idahoensis* association to the more arid sites dominated by the *Artemisia tripartita/F. idahoensis* association. He also took no apparent notice of crossing from the communities in Lincoln County dominated by *A. tripartita* into the much larger zone to the west dominated by *Artemisia tridentata* (Figure 2).

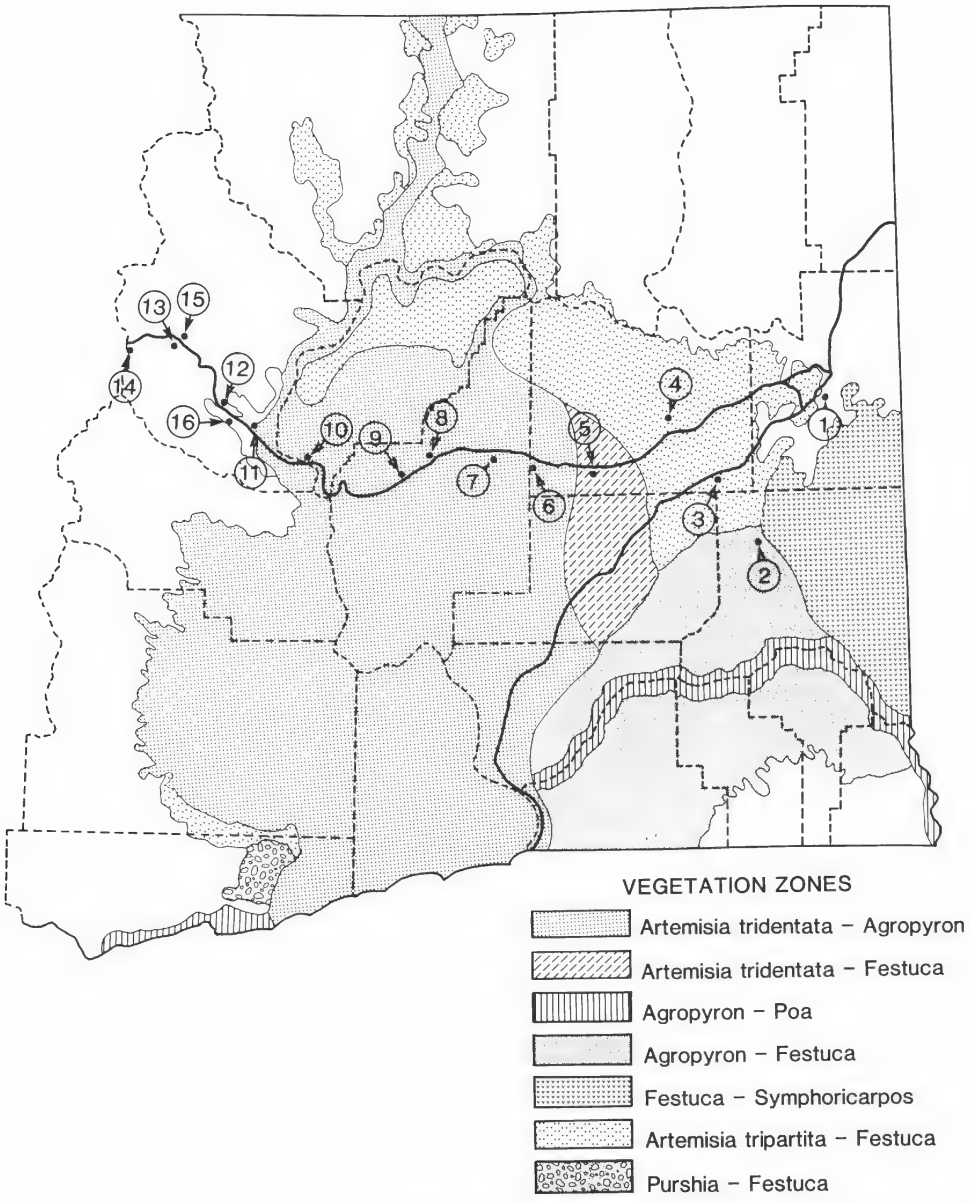

Figure 2. The westward trek of Sandberg and Leiberg's expedition across the Columbia Plateau in relation to the steppe zones according to Daubenmire (1970).

District III

Entering the Columbia River Valley at the Douglas-Chelan County boundary the expedition encountered outliers of the forests that cover the Cascade Range. The flora in their District III reflects the transition between steppe and coniferous forest: open forests of *Abies grandis, Pinus ponderosa* and *Pseudotsuga menziesii* occupied the north and west facing slopes, while steppe communities dominated by *Artemisia tridentata* and *Purshia tridentata* occupied the south and east slopes in a 11-13 km wide swath. Shrubs (e.g., *Acer glabrum* var. *douglasii, Ceanothus velutinus, Ceanothus sanguineus, Spiraea douglasii*) extended from the stream courses into these open forests. Although this district included extensive overlap in the distribution of species more typical of the steppe or forest, Sandberg and Leiberg recognized some characteristic herbaceous species. These included *Aster conspicuus, Erigeron divergens, Lomatium nudicaule, Madia sativa, Phacelia procera, Solidago missouriensis* and *Stachys mexicana.*

District IV

This district encompassed most of the forests in the Cascade Range, a diverse array of forest communities that Sandberg and Leiberg did not differentiate in detail. Their general description of the elevational distribution of major conifers agrees however with the modern distribution of the forest communities and requires no elaboration: *Pinus ponderosa* and *Pseudotsuga menziesii* dominating communities at the lower elevations; *Abies lasiocarpa* and *Pinus albicaulis* at higher elevations. *Tsuga mertensiana* and *Thuja plicata* occurred along stream courses.

Leiberg was much impressed with the extent to which the forests on the eastern slope of the Cascade Range were being destroyed by fire. He remarked that these forests, "... are in a much more rapid and thorough process of extermination than in any other portion of the Pacific Northwest." So extensive were the fires set by prospectors that one could, "Climb any peak in a supposed or proved mineral district during the summer, and you will see the clouds of smoke from the burning forests roll up from many a valley or mountain side." Fires were also started accidentally by trains and settlers. Burned sites often displayed poor tree regeneration for years after a fire and were instead dominated by grasses or shrubs. If the prominence of fire along Sandberg and Leiberg's route was representative of the extent of 19th century burning on the eastern slope of the Cascade Range, this area would have supported few mature forest stands even before wholesale logging in the 20th century.

The Agricultural Setting

Much of the Columbia Plateau is in the rain shadow of the Cascade Range. As a result, annual precipitation is lowest at the eastern base of these mountains but rises eastward. In an era in which irrigation was confined to small systems of ditches in river valleys, the Basin's agriculture was dictated almost completely by this orographic influence. Within the area they trekked, Sandberg and Leiberg found the most extensive agricultural areas in northern Douglas County and northern and eastern Lincoln County. West of southern Lincoln County wheat fields were confined to the valleys, and they saw only one small irrigated field west of Camp 7. Throughout the region, wheat was the main cereal grown, followed by oats, barley and corn. Rye was locally prominent in eastern Washington.

The flanks of the Columbia and Wenatchee Rivers were primarily devoted to orchards and gardens. In 1893 most of the Plateau had been farmed less than 20 years, and Sandberg and Leiberg's list of the crops they saw reflects the newly-arrived farmers' wholesale experimentation. Orchard crops included apples, pears, plums, cherries, peaches, grapes, raspberries, gooseberries, currants, blackberries, strawberries, and mulberries. The list of row crops was even more extensive: peas, beans, carrots, turnips, parsnips, onions, beets, cabbage, celery, asparagus, lettuce, potatoes, parsley, squash, melons, pumpkins, cucumbers, cauliflowers, tomatoes, radish, and mustard. Hops were also being grown, but as Leiberg assiduously pointed out their role was "as [an] ornamental plant only."

Attempts were also being made to raise trees in "tree claims," i.e., small trials of ornamental trees, on the largely treeless Columbia Plateau. *Acer negundo,* followed by *Robinia pseudoacacia,*

and cultivated *Populus* spp. were the most commonly planted species. Almost all the Box elders Sandberg and Leiberg examined in these trials were dead or dying, while the locust and the poplars appeared much more successful.

Alteration of the Steppe

Even by 1893, the combined effects of livestock, cereal agriculture and the importation of alien plants were causing extensive alteration of the steppe (Mack 1981). Sandberg and Leiberg were in the unique position to assess the effect of these alien species as well as the response of the native flora to recurring disturbance. Much of the grazing area in eastern Washington was already fenced and overgrazed. The pattern of overgrazing was more localized in the central and western parts of the Columbia Basin because livestock could not venture far from the few water holes. As a result, large tracts still remained largely ungrazed.

In Leiberg's opinion, few native species even tolerated grazing; fewer still persisted on a site after it was plowed even once. Lacking thorns or other protective structures, many plants were destroyed through grazing and trampling. Still others, such as *Lomatium* spp. and *Camassia quamash* were rooted up and eaten by hogs. Exceptions were *Geranium viscosissimum,* because of the viscous trichomes that cover the plant, and *Balsamorhiza sagittata* with its coarse leaves. Other species he considered able to resist grazing were *Chrysothamnus nauseosus* and *Chrysothamnus viscidiflorus;* both are still prominent members of frequently grazed rangelands (Daubenmire 1970).

In contrast, a few native species were becoming more prominent as a result of increased disturbance. Among these species were a "few Astragali, a *Gilia* or two, and above all *Sisymbrium incisum* [*Descurainia richardsonii*"], which becomes the most ubiquitous and pestiferous of all in run down pastures and impoverished soil generally." *Amsinckia intermedia* and *Lappula redowskii* were both weedy plants and were "excessively common along roadsides and around houses, though not at all conspicuous in the unbroken soil of the plains." *Deschampsia danthonioides* and *Festuca microstachys* were "invariably the species that replace" more palatable species; the fescue already occupied much of the Columbia River Valley because of grazing. In addition, *Descurainia californica* and *Gnaphalium palustre* had also become prominent with livestock grazing and trampling. The roles Leiberg attributed to *A. intermedia* and *D. californica* are surprising because Hitchcock *et al.* (1959, 1964) consider both species rare in the Pacific Northwest. *Lupinus sericeus* became weedy and robust in abandoned or uncultivated fields. *Matricaria matricarioides,* one of the few natives of the Pacific Northwest that has become naturalized elsewhere (Baker 1972), was also part of this native weed flora.

Despite apparent increases in the abundance or distribution of a few species, the overall prominence of the native flora already seemed to be diminishing: "The native plains flora is rapidly disappearing around the cultivated areas, very much more rapidly and thoroughly than seems to be the case east of the Rockies. It does not as a whole appear to possess much resisting power and when brought into competition with eastern invaders generally succumbs." Among the naturalized species were *Amaranthus albus, Amaranthus retroflexus, Anthemis cotula, Artemisia vulgaris, Bromus secalinus, Bromus mollis, Vaccaria segetalis, Verbascum thapsus,* and *Erodium cicutarium,* which had arrived on the Columbia Plateau at least 50 years earlier (Mack 1986). The common sunflower (*Helianthus annuus*), a common escape from cultivation, had already become established on river banks in the Columbia Valley and occurred locally on upland sites. Other alien species they collected on the Columbia Plateau include *Alopecurus pratensis, Barbarea vulgaris, Capsella bursa-pastoris, Lactuca serriola, Rumex crispus, Stellaria graminea,* and *Xanthium strumarium.* Sandberg and Leiberg encountered less than half the alien species Suksdorf (1892) listed for southcentral Washington. This difference probably reflects the comparatively recent settlement of the area through which they passed compared to the lower Columbia River Valley where Suksdorf resided.

Somewhat paradoxically Leiberg did not foresee a rise in the prominence of alien plants despite the weak ability of the native species to tolerate disturbance: "In general the native flora when exterminated is not abundantly replaced by weeds from elsewhere, and such immigrants as are present do not show any troublesome feature or appear in sufficient quantities to be

of economic importance in any locality along our route." The situation was soon to change drastically. By 1929 there were about 200 alien species on the Columbia Plateau, and vast areas had already become dominated by alien plants (Mack 1986).

Among Sandberg and Leiberg's collections was the alien species most characteristic of this regional transformation in the vegetation, *Bromus tectorum* (cheatgrass). Their collection (No. 191) of cheatgrass near Ritzville is the earliest record of this grass in the Pacific Northwest south of British Columbia. Cheatgrass probably arrived by several means, but it may have first entered the region as a seed contaminant in wheat because Ritzville was the center of an early wheat-growing district. This grass was repeatedly introduced in the region, and by 1930 it had become a dominant in the steppe of the Intermountain West (Mack 1981).

Leiberg's Observations on the Regional Geology

A plant taxonomists, study of the regional geology was not within Sandberg and Leiberg's instructions. Not surprisingly Leiberg often gave a contemporary explanation or his own interpretation for the origin of much of the regional geology. He incorrectly believed that much of the underlying granitic rock in the Columbia Basin had been metamorphosed. In addition, he erroneously assumed (along with most of his contemporaries) that the region's loessal soils were derived from the underlying basalt.

Leiberg did however correctly interpret the eastern Washington landscape as having been extensively, although indirectly, altered by glaciation. "Coulees"—dry waterfalls, obviously carved into basalt by tremendous fluvial action—are conspicuous in eastern Washington. Leiberg speculated that the coulees were widened and accentuated along previously-formed cracks in the basalt, through which water passed in the "glacial epochs." He hypothesized that the Columbia River had been dammed temporarily south of its juncture with the Methow River and that the river then overflowed its banks, discharging water over the plains with enormous erosional force. Leiberg correctly interpreted the large amounts of "boulder drift" (till) and granitic gravels as representing considerable water transport from above the Columbia River. Flooding on the scale Leiberg envisioned did occur in the Pleistocene, but the damming was not confined to the Columbia River. Ice lobes of Cordilleran ice dammed several rivers in the region, most notably the Clark Fork to the east. The numerous basalt boulders in northwestern Douglas County that he believed had been moved by a stream with extremely high carrying capacity are instead erratics left from the terminal moraine on the Okanogan lobe in the late Pleistocene (Richmond *et al.* 1965). Despite the shortcomings in some of his geological interpretations, it is nonetheless remarkable that Leiberg envisioned the major events associated with scabland flooding more than 25 years before the appearance of the first of Bretz's classic reports (1923, 1959).

Conclusion

Any further erection of dams along the Columbia River, construction of highways and gaslines, and the ambitious plans to expand the acreage under irrigation in the Columbia Basin will inevitably increase the value of Sandberg and Leiberg's collections and Leiberg's account. The biological loss caused by this activity can be dimly perceived by realizing how inaccurate our understanding of plant distribution and community organization would be if botanical inquiry on the Columbia Plateau had begun in the 1980's instead of almost one hundred years earlier. The geographical limits to the distribution of *Artemisia tridentata,* the diversity and composition of many of the lithosolic and riverine communities, and the role of native species in succession would be virtually impossible to decipher if based on the modern remnants of the vegetation (Daubenmire 1970, Mack 1981). How many misconceptions about the ecology of any region have been unwittingly introduced in the literature through our failure to realize that the landscapes we study have often been extensively altered before serious investigation began? To ignore the historical record, however fragmentary, is to increase unnecessarily these misconceptions.

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Sasquatch Footprints: Can Dermal Ridges be Faked?

Introduction

In May 1987 six very fresh giant human-like footprints (approximately 45 x 15 cm) were discovered in the Blue Mountains of southeastern Washington State by myself and a student. These tracks resembled those that have been reported throughout the Pacific Northwest and which some attribute to the Sasquatch, or Bigfoot, a legendary, bipedal, human-like creature (Green 1978). With the exception of a single scuff mark, and one print over a bent shrub, each footprint was a complete, very clear impression, approximately one centimeter deep in the firm damp soil of the trail, or somewhat deeper in the softer soil beside the trail. These particular tracks were of special interest because they were extremely fresh and because upon close inspection they were found to contain distinct impressions of dermal ridges. Dermal ridges are the tiny swirls or concentric ridges on palms and digits of hands and feet that leave "finger prints" or "toe prints." Such friction skin is found only in primates.

Given the presence of the ridges, the general crispness of the footprints, and the fact that it had been raining lightly during the afternoon the prints were found, it seemed likely that the prints were perhaps only a half-hour old when first found. Unfortunately, the ridges did not transfer to plaster of Paris castings that were made the following day. These casts were made by Paul Freeman who, unlike us, had the necessary materials with him.

However, several years earlier, in June of 1982, plaster casts made by Paul Freeman, then a U.S. Forest Service patrolman, from similar tracks in the same general region did yield distinct dermal ridge impressions. Casts of these earlier tracks were analyzed by several dermatoglyphic experts (including Douglas M. Monsoor, a Colorado criminologist; Robert D. Olsen, with the Kansas Bureau of Investigation, and Edward Palma and Benny Kling, with Wyoming law enforcement offices) who all concluded that it would be extremely difficult, if not impossible, for someone wishing to make fraudulent "Sasquatch" tracks to also produce such fine detail as these ridges (Krantz 1983). They all found the pattern consistent with foot arrangements, and not patched together from several hand impressions. Even though Krantz's analysis of the 1982 casts led him to discount the possibility of deliberate faking in that case, the circumstances of the 1987 tracks led me to test the feasibility of artificially producing prints of dermal ridges. I was especially puzzled by the remarkable perfection of the tracks and their distribution along the trail. Although the tracks were randomly distributed along a quarter-mile stretch of trail over basically uniform ground, only a single pair of sequential left-right prints were found. The other associated print was a single scuff mark found 10 meters up the trail from a print very deeply pressed into the center of the trail. It was difficult to explain why so few tracks were found on so much available soft soil. The possibility that they had been artificially planted could not be ruled out, but it was necessary to account for the presence of the detailed dermal ridge impressions.

Krantz (1983:72) reported that some critics had speculated that dermal ridges could be produced using rubber castings. He also observed that the wind-blown loess topsoil of southeastern Washington was fine enough to hold the imprint of dermal ridges and demonstrated with his own thumbprint that ridges could be transferred from skin-to-soil and then to a plaster cast. I was interested to see if entire footprints could be produced, complete with such ridges. The purpose of this experiment was to determine if dermal ridges could in fact be produced in a deliberately faked footprint.

Methods

In order to produce dermal ridges, a mold of a 44 cm sasquatch-like footprint was shaped from modeling clay. I then carefully rolled my bare big toe in the soft clay to leave clear dermal ridge impressions. I rolled my heel across the heel of

the mold, and imprinted my forehead on the center of the clay footprint. Additionally, impressions of hand and feet skin were made with Elmer's glue and dried pieces of glue pressed into the clay. Plaster of Paris was then poured into the mold and allowed to harden. Upon removal, impressions of dermal ridges were clearly visible in the resulting cast. An outline of the track was then traced on the damp ground, the soil beneath was loosened with a screw-driver, and the plaster cast was pressed firmly into this prepared soil. In order to make a good impression, it was necessary to stamp on the cast. (The cast was broken in the process, but this seemed not to affect the impression). Fresh plaster was then poured into the impression in the soil, and the second cast was examined. It also faithfully reproduced the dermal ridges that were imprinted into the original clay mold.

Figure 1. Human-like footprint, "Sasquatch," next to shoe of the author. Photograph taken in May 1987 in the Blue Mountains of southeastern Washington.

Discussion

Under the right soil conditions, impressions of dermal ridges can easily be transferred from skin-to-clay, from clay-to-plaster, from plaster-to-soil and finally from soil back into plaster. Even more remarkable was the transfer from first skin-to-glue and then into the same transfer sequence: clay to plaster to soil and into plaster again, although the resulting cast in this case was a "negative" print.

Krantz (personal communication) readily recognized that the resulting cast I produced was a clumsy fake because of the crudely-shaped toes, and seven dematoglyphic experts (certified latent print examiners in Washington, Oregon, and California, and another visitor from Scotland Yard) readily determined that the ridges were not correctly situated.

Dermal ridges can be faked in footprints with relative ease, at least under certain soil conditions. This experiment certainly does not prove that the specific tracks examined in May 1987 were fakes, but it does suggest that any purported sasquatch prints containing impressions of dermal ridges need to be carefully evaluated for the possible presence of patching or other irregularities throughout the entire footprint.

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REVIEW ARTICLE

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Did the Dinosaurs Die or Evolve into Red Herrings?

Introduction

On February 2 of 1986 Halley's comet reached the perihelion, its closest brush with the sun. The last time it approached us was in 1910, when it caused quite a stir, and this time there was an international effort, combining spacecraft from a number of countries, to take a close look at it and determine its properties.

In our present view of the nature of nature we accept comets and other extraterrestrial bodies as natural phenomena, but this was not always the case. For centuries it was believed that all aspects of life on Earth were ruled by the positions of the stars and the planets. Once the locations of the stars and the orbits of the planets were known, the appearance of a new star of any kind seemed a violation of the natural order and hence to be a harbinger of disaster. For example, the passage of Halley's comet in 1066 is recorded on the Bayeux tapestry, which depicts King Harold's followers assuring him that this was not a promise of good things to come; a prediction that proved to be accurate in view of his defeat by William the Conqueror.

A portrait of the same comet is found in Giotto's fresco, Adoration of the Magi, in the Arena Chapel in Padua where it assumes the role of the Star of Bethlehem. The comet made an appearance in 1301, and the frescos appear to have been started in 1303, so the recollection would have been fresh in his mind. The frescos in the chapel were commissioned by the Florentine businessman, Enrico Scrovegni, perhaps to expatiate the sins of his Father who was identified by Dante as the archuserer in his *Inferno*.

In Dante's day the Earth was viewed as flawed, but as one went towards the heavens, one encountered perfection; celestial spheres, unblemished and pure, stretching to the farthest star. The sphere was the perfect shape and the individual heavenly bodies were presumed to be perfectly spherical. The Earth stood at the center of this perfect universe and only on Earth was there imperfection, irregularity, and sin; possibly Earth was the only interesting place in this whole system.

Padua was a center of mathematics, the discipline that would eventually raise astronomy from its roots in the superstitions of astrology. An important contributor to this was Galileo Galilei, who became a lecturer in mathematics at the University of Padua in 1589. In Venice in 1609, he learned of the recent invention of the telescope and on his return home he made one, the first capable of astronomical observations, and turned it on the Moon.

He discovered that it was not the perfect, smooth sphere of the accepted cosmological models. He identified mountains casting shadows so long that their height necessarily exceeded the height of those in his native Italy. He also observed circular depressions but produced no hypothesis to explain them (Drake and Komar, 1984).

Galileo went on to observe the phases of Venus and the moons of Jupiter, and then ran into problems when he espoused the Copernican model in which the Sun, not the Earth, was at the center of the Solar System. This ran counter to the accepted cosmology, which was tied into the catechism of the Church, and he was forced to recant. In principle his observation of irregularities in the Moon had equal potential for disturbing medieval cosmology, for it indicated

that the Moon, as well as the Earth, lacked perfection. But perhaps this was too subtle for the Inquisition.

Sixty-five years after Galileo's initial observations, Robert Hooke trained his telescope on the lunar area called Mons Olympus, sketched what he saw, and described pits shaped like dishes in the text accompanying the sketches published in his *Micrographia* (1665). Hooke advanced two theories to explain the lunar pits based on experiments that he made. In the first experiment he bombarded a mixture of clay and water with a heavy body, and produced pits not unlike those on the Moon. But he could not think of a physical explanation for such bodies striking the Moon and, therefore, he could not accept that this could be the crater-forming mechanism.

He tried a second experiment involving a pot of boiling alabaster. When he removed it from the fire, he noticed that the surface was covered with small pits which bore a resemblance to the pits that he observed on the Moon. He concluded that the Moon, like the Earth, contained subterranean fires which on contact with aerial substances produce great quantities of vapor that explode and shatter the crust; in other words, a steam explosion.

Meteors and Meteorites

Hooke's experiments took place at a time of change in the perception of the nature of nature. In the Age of Reason, supernatural causes for natural phenomena were rejected and rational causes, following natural laws, were sought. The results were not always rational although they were different. For example, the Swiss mineralogist J. A. DeLuc stated that if he saw a fall of a meteorite himself, he would not believe his own eyes. When a meteorite fell on Barbaton in France in 1790 and the fall was witnessed by the mayor and the city council, the French physician and chemist, Claude Louis Berthollet, wrote, "How sad it is that the entire municipality enters folk tales upon an official record, presenting them as something actually seen, while they cannot be explained by physics nor by anything reasonable." (Nininger 1933) The father of modern chemistry, Antoine Laurent Lavoisier, joined with scientists of the Academy of Sciences of Paris to sign a memorandum in 1772 which tried to put an end to irrational interpretations of the origin of meteorites. It concluded that stones to which a cosmic origin had been assigned were actually ordinary terrestrial rocks that had been struck by lightning and that "the falling of stones from the sky is physically impossible." When Yale professors Silliman and Kingsley described a meteorite fall in Weston, Connecticut in 1807, Thomas Jefferson is alleged to have remarked that he would rather believe that those two Yankee professors would lie, than that stones would fall from heaven (Hartmann 1982).

The reality of meteorites was finally established near the end of the 18th Century by the work of the physicists E.F.F. Chladni of Germany and E. Biot of France, and even more by a shower of several thousand stones on the town of l'Aigle in France in 1803 (Nininger 1933). It is hard to ignore experience, even when theory tries to deny it, although noble efforts are sometimes made to do so.

Impact Craters

With the origin of meteorites accepted, many scientists busied themselves with experiments to explain the Moon's craters. Notable among these was the distinguished American geologist, G. K. Gilbert. Gilbert had participated in the earlier Wheeler and Powell surveys in the west and was the best known of the early Geological Survey geologists. By the late 19th Century uniformitarianism had gained many supporters and the Earth was viewed as the product of slow and continuous change through the same kinds of processes that are affecting it today. The Moon was considered along similar lines and most of its surface features were viewed as the result of internal forces. Gradual and prolonged volcanism was credited with the formation of the lunar surface features, especially its craters. Because these craters differed in size, abundance, and shape from terrestrial craters, they were thought to represent a special type of volcanic activity that resulted from the Moon's peculiar physical condition.

When the Director of the Geological Survey, John Wesley Powell, transferred him to Washington to help with administrative tasks, Gilbert sought an outlet for his scientific curiosity by making observations of the Moon through the refracting telescope of the Naval Observatory

(El-Baz 1980). From these observations he constructed the form of these craters; a gentle slope up to a steep rim, a flat floor which lay at a lower elevation than the surrounding plain, and a central peak. Although there were some terrestrial volcanic craters that bore a little resemblance to these lunar features, most were very different and he concluded that "through the expression of every feature the lunar crater emphatically denies kinship with the ordinary volcanoes on the Earth." (Gilbert 1893). In a New York hotel room, during a series of lectures he was giving at Columbia University, Gilbert performed bombardment experiments with clay balls on a clay surface, producing many of the features seen in lunar craters, and he challenged the volcanic theory favored by many geologists (El-Baz 1980).

Having satisfied himself with the impact origin of the lunar craters, Gilbert then turned to the Earth to seek a terrestrial analogue. He was aware of a crater discovered in 1891 in central Arizona, then called Coon Butte, a landmark for locating Coon Springs (Darton 1910), but subsequently named Barringer crater or Meteor Crater. This feature stands out as a striking anomaly in the flat-lying rocks of the plain in which it is located. The Native Americans of the area have several legends about the crater which represent it as the site where the Great Spirit descended in a blazing fire and disappeared beneath the ground (Nininger 1933). Large numbers of fragments of meteoritic iron had been found in the vicinity of the crater, chiefly within two miles of its rim, and Gilbert began his study with the conviction that it was the result of the impact of an extraterrestrial body. His New York hotel room experiments led him to believe that he should find evidence of the large impacting body in the crater, but he could not. Therefore, he reluctantly concluded that the crater was the result of an internal explosion, rather than an impact.

N. H. Darton made a reconnaissance of the area for the Geological Survey a few years later and visited the crater. He concluded, "The hypothesis that it was caused by impact of a meteor ... is in accordance with some of the features but does not accord with the all important fact that no meteor is present, as has been demonstrated by many borings.... It is agreed that if there was a meteor, it must have been at least 500 feet in diameter. The occurrence of a few tons of meteorite iron in the vicinity and mingled with some of the debris on the rim and in the center is an enigma. The hypothesis of Gilbert that the crater and rim were produced by a volcanic steam explosion appeals to me most strongly, notwithstanding its purely gratuitous character" (Darton 1910).

The weight of an iron meteor 500 feet in diameter would be about 7 million tons. Some preliminary assays of the meteoritic iron in the area suggested that it contained alluring quantities of platinum and iridium so a stock company, Meteor Crater Exploration and Mining Company, was formed by D. M. Barringer to exploit the property. A number of excavations and boreholes were made, but they failed to encounter the expected large body. In addition, subsequent assays did not confirm the significant amounts of iridium and platinum. Nonetheless, Barringer was still convinced that the crater had been created by meteor impact. The official Geological Survey line was that it was the result of an internal explosion and Barringer was infuriated when the Survey refused to call it Meteor Crater on its maps.

In the 1950's, Gene Shoemaker, with the Geological Survey, was studying the explosive vents and volcanoes of the Colorado Plateau in an effort to find the ultimate source of the abundant sedimentary uranium deposits. At Los Alamos, Ted Taylor, then a bomb designer and later a professor at Princeton, wanted somebody to study craters produced by nuclear explosions. He asked the Survey for help, and they assigned Shoemaker to the task.

He looked at some of the craters at the Nevada test site and then compared these with Meteor Crater, finding many similarities. The general character of the craters was similar and, in addition, he and his colleagues found that a high pressure form of quartz, coesite, produced by shock pressures greater than 20 kilobars [2 gigapascals], was present (Chao *et al.* 1960). But where was the large meteor? It had remained hidden despite geophysical investigations, excavations and drilling.

Shoemaker (1960) pointed out that Gilbert and earlier investigators had assumed a relatively large body travelling at modest speeds. The kinetic energy of a meteorite is equal to mv^2, so if the meteorite is travelling at high speed, it will

have enormous energy. The energy increases proportionally to the mass, but as the square of the velocity. Using craters created by nuclear explosions of known strength for calibration, Shoemaker calculated that the impact energy that created Meteor Crater was equivalent to 1.7 megatons of TNT. If the meteor were travelling at 10-15 km/sec, within the range of observed velocities, then the mass of the meteorite need be only 63,000 tons and its diameter a mere 25 meters. It is not surprising that a mass this small could not be located, especially considering the breakup that must have resulted when it hit. Gilbert had underestimated the velocity of the impacting body and this in turn meant that he had to grossly overestimate its size.

Subsequently a number of ancient craters were identified, some of very large size like Manicouagin in Ontario, 100 km in diameter, some found during oil exploration buried in sedimentary basins. Others, once called cryptovolcanic and attributed to steam explosions (Bucher 1933, 1963), were reidentified as impact structures.

There was some resistance to acceptance of many of these structures as having been formed by meteorites, but the Apollo program, which produced a large body of information about lunar craters, generated great enthusiasm for the idea and produced evidence that lunar, terrestrial, and explosion craters had many generic similarities. By 1970 the concept had been pretty well accepted and people turned their attention to other matters.

Impacts and Extinctions

Iridium anomalies

The subject came to light again in the late 1970's when Walter Alvarez, a young geologist from Berkeley, ran into a stratigraphic problem in Gubbio, Italy, and was discussing it with his father, Luis, a Nobel Prize-winning physicist. Walter Alvarez was working in a section which consisted of relatively thick limestone units separated by thin shales. One of these shales marked the boundary between the Cretaceous and the Tertiary [K/T], a fundamental discontinuity in Earth history about 65 million years ago. He wanted to find out how much time the shale unit represented and his father pointed out that meteoritic dust is coming in all the time and that it was not unreasonable to assume that the rate is constant. If one could find an element that is rare in the crustal rocks on Earth but present in meteorites and meteoric dust, one could measure the relative concentrations in the limestone and the shale units and calculate the relative deposition rates. This was a clever idea and the element *iridium*, one of the platinum metals, was chosen as the indicator.

When the iridium in the clay layer at the boundary was measured, it appeared to be higher by a factor of 30 than background values; too high, it was thought, to be explained by changes in sedimentation rate. This led to the suggestion that the excess came from the impact of a 10 km diameter asteroid on the Earth's surface (L. Alvarez *et al.* 1980). Such a collision would have an impact energy of about 10^8 megatons [equivalent to about 100 million MX missles]. This much energy, released in a short time, might well be expected to have an effect on life on Earth.

The end of the Cretaceous was a time of major faunal changes as indicated by the fossil record, including disappearance of the dinosaurs and expansion of the mammals, so it was an easy step to suppose that the impact was the cause, an idea previously suggested by de Laubenfels (1956). Perhaps earlier impacts caused earlier extinctions (McLaren, 1970, 1983; Urey, 1973). A scenario was developed in which it was suggested that the dust from the asteroid impact carried around the Earth reducing solar insolation, and with it photosynthesis, cutting back on the plants and starving the animals (L. Alvarez *et al.* 1980, L. Alvarez 1987). When it was pointed out that dust from volcanic eruptions doesn't stay in the atmosphere very long the computer modelers suggested that the impact caused the particles to be blown out of the atmosphere in ballistic trajectories and be distributed around the Earth to reenter later.

Doubts and Objections

This model was met with enthusiasm by some and dismay by others. Few doubt that extraterrestrial objects of considerable magnitude have struck the Earth and, similarly, major paleontological discontinuities in the geological record are universally accepted. What is questioned is

whether there is a direct linkage between the two. It should be noted that K/T time was geologically very noisy: there was almost unprecedented volcanic activity; the Laramide orogeny was beginning to raise the mountains in the West; the great Cretaceous seaway extending from the Gulf of Mexico to the Beaufort Sea was drying up in response to a major regression of the sea from the land: continents were splitting and volcanism was rampant. Ocean circulation was changing as the continental land masses shifted their positions and there were changes in climate. As a result, simple cause and effect relationships are not clear cut nor easy to determine.

Our ability to measure geologically short time intervals in the past is limited and it is very difficult to determine whether an event was instantaneous from the geological record of 65 million years ago. A study of the available evidence appeared to favor activity spread over a time period of the order of 10^4-10^6 years (Officer and Drake 1983). Then, the clay layer was presumed to be the fallout of the dust cloud created by the impact. If so the clay mineralogy of the layer might be expected to be different from that in the rocks immediately above or below. Measurements that were made suggested that the clays were predominantly detrital, with little or no difference in clay mineralogy between those in the boundary clay and those in the beds immediately above and below although they differed from area to area (Rampino and Reynolds 1983). In the Caspian area, for example, the clays above, below, and at the boundary are attapulgites (Herman *et al.*, in press); there is kaolinite at the Gubbio boundary, but spread over 2 meters of section representing several hundred thousand years (Johnson and Reynolds 1985). Other sections have similar characteristics. Perhaps the amounts left by the proposed impact are mixed with these, but were too small to leave a significant record. Maybe none are there.

Then, too, latest Cretaceous dinosaurs were found to have inhabited the North Slope of Alaska, at paleolatitudes of 70-85°N. Although the climate at these latitudes was much more equitable than at present, these saurians would have had to endure annual variations in solar insolation, temperature and food supply of more extreme and of longer duration than that proposed by the impact dust cloud theory of extinctions. Perhaps they were migratory, although the presence of juveniles suggests that they occupied high latitudes year round (Brouwers *et al.* 1987).

Bolides or Volcanos?

In a paper in EOS Walter Alvarez (1986) spelled out the evidence favoring an impact. He cited iridium, spherules, shocked quartz, soot, and worldwide distribution as reasons for accepting impacts and rejecting volcanism as a cause of the K/T extinctions. If we look at each of these, we find that the evidence may not be as compelling as suggested.

Iridium Enrichment

Initial description of the iridium anomaly described it as a spike confined to a very short time interval at the K/T boundary; the distribution to be expected from an instantaneous event reworked by bioturbation (L. Alvarez *et al.* 1980). Some questions were raised about the uniqueness of the anomaly because the measurements are not easy to make and most had been made at or near the boundary.

Subsequent measurements showed anomalous iridium over a considerably longer sedimentary interval, sometimes with multiple peaks, and sometimes not synchronous with the paleontological boundary (Crockett *et al.* 1986, Hansen *et al.* 1986a, Kyte and Wasson 1986, Michel *et al.* 1985, Nazarov *et al.* 1983, Preisinger *et al.* 1986, Rast and Graup 1985, Rocchia *et al.* 1984). This distribution does not conform so well with the concept of an instantaneous event.

Schmitz (1985) suggested that redox-controlled precipitation processes were important in determining metal enrichment at the K/T boundary in Denmark and suggested that similar processes may have affected the boundary in Spain and New Zealand. In a more recent study, Schmitz *et al.* (submitted for publication) found iridium concentrations in kerogen separated from the fish Clay at Stevns Klint to be 1100 ppb and similar high concentrations in the K/T boundary clay at Caravaca, Spain and suggested that bacterial action has influenced metal accumulation. Rucklidge *et al.* (1982) found that the iridium in the K/T of Denmark was concentrated in the organic fraction (dominantly dinoflagellate cycts).

It is true that iridium is rare in the crustal rocks of the Earth, but it is not so rare in the Earth's mantle. Observations at Kilauea (Zoller *et al.* 1983, Olmez *et al.* 1986) indicate that volcanism from deep in the mantle has produced an iridium enrichment in the volcanic plume of 10^4-10^5 over that in Hawaiian basalts. The iridium appears to be carried as a fluoride and in this volatile phase has the opportunity for wide distribution. Thus hot spot volcanism from deep in the Earth's mantle is a strong candidate as a possible source of the anomalous iridium.

Luck and Turekian (1983) suggested that the $^{187/186}$Os ratio might be used to differentiate between extraterrestrial or terrestrial sources and to identify an impact. Their results, and others to date, indicate that a crustal source does not fit the data, but that either a mantle source or multiple impacts, rather than a single impact, would.

Thus it is hard to conclude that the presence of iridium uniquely demonstrates an impact. The osmium isotopes and their distribution would seem to require more than one, but both the osmium and the iridium could also be explained in terms of a source in the Earth's mantle.

Many of the K/T sections are incomplete due to the major regression of the sea that was taking place but in some, that appear to be complete, the transition from Cretaceous nannofossils to Tertiary, like the iridium anomaly, does not occur abruptly but over a considerable interval of time (Perch-Nielson *et al.* 1982. Theirstein 1981). Maybe the iridium was not deposited in a geological instant; maybe it has been spread around by geological processes; or maybe, as has been suggested recently, it came from comet showers lasting 10^4-10^6 years (Hut *et al.* 1987).

Microspherules

Spherules, generally ranging in size between 100-1000 μm, have been cited as evidence for the impact (Smith and Klaver 1981, Montanari *et al.* 1983). Some spherules found in deep sea cores seem to be clearly of cosmic origin (Clayton *et al.* 1986), although their rate of deposition seems to vary over time by several orders of magnitude. There was considerable interest in spherules in the 1960's, when the first Moon data were appearing, and comparisons were made between spherules from explosive and shield volcanoes and those presumed to be extraterrestrial (Hodge and Wright 1965, Heiken and Lofgren 1971). They seem to be present in both shield and explosive volcanoes and they all appear to be quite similar in major element chemistry.

Most of the spherules at the K/T boundary are considered to be secondary—replacements of something—and it is not always easy to guess what that something was (De Paolo *et al.* 1983, Montanari *et al.* 1983 (Varekamp and Thomas 1982). Hansen *et al.* (1986b) concluded that K/T microspherules from Denmark, New Zealand, and Spain were diagenetic replacements of prasinophyte algae. In New Zealand goethite spherules were found, probably derived from pyrite (Brooks *et al.* 1985). Bhandari (written communication) found that the microspherules at the K/T boundary in Mangyshlak, USSR, are glauconite. At Caravaca the K-spar spherules (possible from alteration of glauconite) have a core of goethite (Smit and Klaver 1981, Hansen *et al.* 1986b).

Naslund *et al.* (1986) found that while K-spar spherules were more numerous at the K/T boundary at Gubbio, they are also found in the clay layers both above and below the boundary, covering a time span of at least 20 million years. If this is true, they are hard to relate to a single impact, or even a comet shower. Vanucci *et al.* (1981) also found an extended distribution at Gubbio and from their composition concluded that the spherules were of volcanic origin. If they are primary, and not the result of diagenesis, perhaps extended volcanic activity would be a more plausible source than a short term event.

Recently the situation has become more confusing as Izett (1987) has concluded that the spherules in the Raton Basin and at Caravaca, Spain, were unrelated to a possible impact because they fall below the iridium horizon while Bohor and Triplehorn (1987) think that the spherules stayed in the lower atmosphere after the impact and fell to Earth before the iridium-rich layer which was blown out of the atmosphere. Hidebrand and Boynton (1987) found that the absolute abundances of rare earth elements in the "non-impactor" part of the boundary layer can best be explained by a mixture of thick sediments and upper mantle materials and suggest an oceanic impact site near a continental margin. One might wonder what kind of rare earth

element abundances would be expected from volcanism from deep in the mantle beneath a sedimentary basin.

Shocked Minerals

Common wisdom implies that shocked minerals are indicative of impacts and they have been found in some abundance in boundary clays at a number of localities in western North America (Bohor *et al.* 1984, 1985; Izett and Pillmore 1985; Lerbeckmo et al 1979; Lerbeckmo and St. Louis 1986). The distribution and the size of the grains [up to 0.58 mm] suggests a continental source in the Western United States although the isotope work of DePaolo (1983) suggests an oceanic impact site. The Manson structure in Iowa was suggested as a possible candidate site since it is about the right age and may be an impact structure, but it seems to be too small (32 km) to be the record of the global extinction event.

In the 1960's it was concluded that shocked minerals could not be produced by volcanoes because the models of volcanoes suggested that pressures were not sufficiently high. There is little evidence, however, that volcanic debris was ever examined for shocked minerals. Carter *et al.* (1986, 1987) examined volcanic ash from the major eruption of Toba 75,000 years ago which Kent (1981) concluded had 40% of the energy of the proposed impact, and found shocked minerals, including quartz. They concluded that pressures reached at least 10 Gigapascals.

Bohor *et al.* (1987) disclaims Toba because amounts of shocked quartz are so small. They report 25% at Brownie Butte, 40% in GPC-3, 30% from the Raton Basin. In this paper they claim that a common average for all K/T boundary clays studied is about 25% although earlier (Bohor and Izett 1986) reported low or very low ratios of shocked to non-shocked quartz at sites in Europe and New Zealand. If both statements are true, the "common average" is deceiving.

Investigation of the Bishop tuff from the eruption of the Long Valley caldera in California 600,000 years ago also revealed shocked minerals including feldspar, mica and some quartz (Carter *et al.*, in press). Most of the shocked quartz grains from volcanic explosions found to date have only single planar features while many of those described in Western North America contain multiple planes. This is taken as an argument in favor of impact and this may be the case in and near western North America, but abundances elsewhere are too low to allow definitive statements.

Still more recently Carter examined an extended part of the Gubbio section and found shocked minerals over a considerable range (Hallam, 1987). The distribution is difficult to relate to a single impact, but might be more appropriately associated with extended and extensive volcanism. Maybe shocked minerals are more abundant in the sediments than we think; perhaps we should look for them.

Soot

A paper in Science by Wolback *et al.* (1985) suggested that graphitic carbon found at the K/T boundary represented soot from wildfires started by an impact that produced an asteroidal winter. It was claimed that the *flux* of "soot" at the boundary was 10^3-10^4 times "normal" values. If you read the fine print in this article, the reason that the soot flux is in excess is because it was assumed that the boundary clay layer was deposited in one year while the layers above and below were taken as deposited at rates of cm/1000 years. The only comparisons given were for the Stevns Klint section in Denmark where there is about 4 times as much carbon in the K/T layer as there is in layers above and below. This is a messy section in which there has clearly been carbonate solution at the boundary (Ekdale and Bromley 1984). If one makes a different assumption—that the clay kept coming in at a constant rate— and then compares the clay content of the limestones with that of the boundary clay, one would actually get a lower carbon flux at the boundary.

Global Distribution

Finally, we come to the question of worldwide distribution. In the asteroid model, the energy is reputed to have blown a hole through the stratosphere and allowed fairly large particles to circle the Earth. Could volcanoes distribute things as widely?

We know from satellite observations that aerosols from explosive volcanoes like El Chichon may reach elevations of 40 km and circulate around the world (Clancy 1986), but we haven't

found much iridium associated with this type of volcano as yet. A reasonable question that might be asked is whether iridium from hot spot or flood basalt volcanism could circulate very far. Zoller *et al.* (1983) and Olmez *et al.* (1986) believe that iridium is in a volatile phase, possibly a fluoride, but flood basalts are quite different from explosive volcanoes.

Recently Stothers *et al.* (1986) concluded from plume theory, applied to observational estimates of the rate of thermal energy release from large fire fountains, that flood basalt fissure eruptions that produce individual flows with volumes of >100 km^3 at very high rates have the potential to inject aerosols into the lower stratosphere with potentially drastic short-term consequences. If the iridium is carried as a volatile, one could expect it to be carried considerable distances in the atmosphere. The configuration of the continents at K/T time permitted rapid global circulation of the ocean surface waters in low latitudes, and one could anticipate further distribution by this means. This model would suggest that iridium from hot spot volcanism could have been widely circulated at K/T time.

Volcanoes or Bolides?

Thus it would appear that most of the features attributed to a bolide can also be explained in terms of purely terrestrial phenomena and that prolonged volcanism would better fit the data than an instantaneous event. The very large crater that would be expected from the impact of a 10 km bolide has been very elusive. But maybe it's buried somewhere or has been mashed up by geological processes. The isotope data (De Paolo *et al.* 1983) support the idea of an oceanic impact and maybe the crater hit there and then was subducted, although an ocean impact would present some problems with the shocked quartz which suggests a continental site. Maybe we aren't looking for the right thing; maybe it produced volcanism which has hidden it, although the volcanism associated with impacts on the moon seems to be pretty much confined to the interiors of the craters.

What Was The Question Again?

In the skirmishing these days about phenomena that may be associated with impacts or with volcanism the primary question sometimes gets lost. It is where there is any relationship between impacts and the extinctions of organisms found in the fossil record. The answer is most likely to come from paleonecrology, the study of the extinctions themselves.

What Happened at the K/T Transition?

The K/T boundary was defined a long time ago by the stratigraphers from disappearance of some fossils and appearance of others. The K/T extinctions do not all seem to be instantaneous, but are spread over 10^3-10^5 years in the geological record and not necessarily synchronous. They were selective; obviously everything didn't die or you wouldn't be reading this. Most of the large and naked died, but most of the small, the furry, and the feathered survived despite their higher metabolism rates. The last of the dinosaurs seem to have died at about that time, but not the turtles, salamanders, or crocodiles. The monotremes suffered grievously, but not the other mammals.

It is very difficult to figure out exactly when the dinosaurs died out because we have found few of them left by the end of the Cretaceous. This was geologically a very spirited time in Earth history and there has been no shortage of ideas about the causes of their extinction; senescence, sea level or climate change, competition from mammals, starvation after the impact, volcanic activity, etc. Many organisms, including the dinosaurs, were in a long period of decline before the extinction came and may have disappeared through other causes. Many other organisms did not die at the end of Cretaceous time. Why did they survive and others throw in their hands (or fins or hooves or paws)?

Selective Extinctions

A sweeping extinction of ecologically unrelated organisms resulting from a protracted period of darkness, as postulated by the asteroid impact hypothesis (Alvarez *et al.* 1980), apparently did not occur at the close of the Cretaceous. In fact, land, fresh water, and marine noncalcareous photosynthetic organisms which should have been most affected by an extended blackout crossed the boundary unscathed (Archibald 1981, *in* Russell and Rice, eds., 1982; Van Valen 1984, *in* Berggren and van Couvering, eds., 1984; Hickey 1981; Hickey *et al.* 1983; Van Valen and

Sloan 1977; etc). Extinctions were selective, affecting approximately 90% of the warm-water calcareous phyto- and zooplankton genera in the Tethyan-Paratethyan regions (Tappan 1982; Herman *et al.,* in press). These highly diverse taxa with many endemic representatives were at the peak of their evolutionary development. The coccolithophore Braarudosphaera and the calcareous cyst-producing dinoflagellate Thoracosphaera survived the late Cretaceous environmental crisis; both have living representatives and are considered tolerant of a wide range of habitats. These "survivors" are most common in the basal Danian in mid and high latitude deposits, but are scarce in low latitude sediments (Tappan 1979, Perch-Nielsen *et al.* 1982). A similar pattern was observed in planktonic foraminifera. Following the nearly complete annihilation of the entire group at the end of the Cretaceous, one survivor was found in the earliest Tertiary sediments (Smit 1982). This species was either tolerant to a wide range of environmental conditions or was a subsurface water inhabitant. Higher latitude forms seem to have carried on with less attrition; noncalcareous ones, particularly the diatoms, silicoflagellates and radiolarians, diversified at the end of the Mesozoic era. Other groups of organisms, gradually declining throughout the Cretaceous, died out at the K/T boundary. They include the ammonites, belemnites, inceramid bivalves and rudists (e.g. Emiliani *et al.* 1961; Russell and Rice, eds., 1982; Berggren and van Couvering, eds., 1984). Benthonic foraminifera, scaphopods, gastropods, nautiloids, bryozoans, brachiopods, marine turtles and irregular echinoids exhibit only gradual extinction across the boundary (Tappan, 1982; Herman *et al.,* in press). Extinctions of fresh water fish were selective (Russell, 1979).

Arthur *et al.* (1987) noted a decrease in marine primary productivity for a period of as long as 1.5 MY near the K/T boundary. Accompanying this was selective attrition of organisms that depended directly upon the flux of organic matter as a food source as opposed to detritus or deposit feeders who could live off the accumulated organic carbon. It's fair to ask whether this was the result of a short lived dust cloud from an impact or of an event or events of longer duration.

Paleo-oceanography

While dinosaurs have great PR value, they are not the most definitive creatures to use for describing the event because they were already in decline and because we have found so few of them. Marine organisms are much more numerous and widely distributed and have a faster turnover time, so they should be better indicators. Therefore it is useful to examine the paleooceanography of K/T time.

The positions of the continents in K/T time would permit ready global exchange of surface waters at low latitudes in the Northern hemisphere Berggren and Hollister 1981). The paleooceanographers tell us that bottom temperatures in the deep ocean were warm and deep circulation was sluggish, probably salinity driven rather than temperature driven like today (Berger 1979). It would seem possible, if the relative time constants were right, to introduce something into the surface waters at low to mid latitudes that would have its major effect on the calcareous-shelled planktonic organisms, but would have less effect on the benthic ones, the siliceous-shelled forms, or the higher latitude organisms.

In the modern ocean the surface waters are supersaturated with calcium carbonate, but in the ocean depth the waters are undersaturated and at the carbonate compensation depth [CCD], which depends upon temperature and the partial pressure of CO_2, the $CaCO_3$content of the sediment goes to zero; the $CaCO_3$ dissolves out.

At K/T time, there is confusion about what happens to this CCD at K/T time. Some have argued that it stayed deep while others have suggested that it came up to the surface and then rapidly descended again (Worsley 1974). This latter would require the addition of a very large quantity of H^+ ion because the buffering capacity of the whole ocean is very large. But if the ocean were strongly stratified at that time (Berger 1979) with sluggish deep circulation, a short term acidifying event would only have to affect the mixed layer of the surface ocean to make life difficult for the calcareous shelled organisms that live in these surface waters, but to have a lesser effect on the benthic organisms who live below the mixed layer. The reduction of carbonate production in near surface waters would result in an apparent upward excursion of the CCD (Arthur *et al.* 1987).

Smit and Romein (1985) have noted that the Cretaceous planktonic foraminifera tend to disappear first, followed by the coccoliths over a more extended period of time. Studies indicate that the growth of modern foraminifera is inhibited when the pH reaches 7.6-7.8 while modern coccolithophoridae have problems producing tests when the pH reaches 7.5 and do not survive below a pH of 7.0-7.3 (Phleger and Bradshaw 1966; Boltovsky and Wright 1976; McLean 1985; Sikes and Wilbur 1980, 1982; Sikes *et al.* 1980). It has been shown that an abrupt increase in the rate of calcite dissolution in ocean water occurs at a $\triangle$pH of 0.08 (Takahashi 1975).

If there is a lowering of the pH, we would expect the forams to go first and the coccoliths later. The replacing Tertiary foraminifera are small and simple. (Perch-Nielsen *et al.* 1982, Russell 1982). For modern plankton small forms survive better in a lower pH environment than large forms (Boltovsky and Wright 1976), and an environment which is undergoing change is selective toward smaller species as compared with a more stable environment (Kilham and Kilham 1980)

Organisms not dependent upon carbonate, such as dinoflagellates, silicoflagellates, or diatoms would be less affected (Gensemer and Kilham 1984). Some dinoflagellates live in lake waters with a pH of 4.0 (Tappan 1982). We have to be a little careful, of course, when we deal with paleonecrology, because we are rooting around in the graveyard, not examining the organisms themselves.

Isotopic Indicators

MacDougall (1988) interpreted a significant excursion in ratio of ^{87}Sr to ^{86}Sr as an indication of greatly increased continental weathering due to acid precipitation following a large bolide impact. He based his conclusion on data from Hess *et al.* (1986), but did not use the detailed data from Koepnick *et al.* (1980) which indicate that the excursion began well before the K/T boundary. The complete data make it difficult to associate the data with an impact at K/T time (Officer *et al.,* in preparation).

Oxygen isotopic composition of the carbonate shells of foraminifers and coccolith plates in marine sediments provide the combined record of past ocean water temperatures and the isotopic composition of sea water (e.g. Duplessy 1978). Among the factors conditioning and modifying sea water composition, temperature, salinity, precipitation, river runoff, evaporation and convective mixing are considered important. In marine deposits that contain continuous sequences of latest Cretaceous and earliest Tertiary sediments, the oxygen isotopic composition of planktonic forminiferal shells and bulk sediments (made up principally of nannoplankton and microplankton skeletal fragments) at the boundary show remarkably sharp oxygen isotope shifts (Perch-Nielson *et al.* 1982; Herman *et al.,* in press). Although diagenetic effects cannot be ignored (Hallam 1987), this signal can be interpreted in terms of paleotemperature and suggests that the isotopic enrichment at the K/T boundary can be attributed primarily to a sudden temperature drop while the ^{18}O depleted sediments in the overlying Early Danian suggest a warming trend of the surface ocean water.

The distribution of $\delta^{13}C$ is controlled by the primary productivity in near surface waters and oxidation of organic matter and generation of CO^2 in deep waters (Kroopnik 1980, Williams *et al.* 1977). A large and rapid negative shift in $\delta^{13}C$ values is found for planktonic foraminifera at the K/T boundary although the magnitude varies with location (Perch-Nielson *et al.* 1982, Scholle and Arthur 1980). Benthic forms do not indicate this negative shift and, indeed sometimes exhibit the opposite trend (Boresma and Shackleton 1981) extending over a longer time period.

The evidence indicates a rapid diminution in primary productivity near the K/T boundary (Hsu *et al.* 1982). Bramlette (1965) and Tappan (1968) suggest nutrient starvation as a cause; others have related this to climate change as indicated by the paleotemperatures (Emiliani *et al.* 1981, Fisher and Arthur 1977, Stanley 1984) although Arthur *et al.* (1987) do not feel that there is consistent, irrefutable evidence for major temperature changes across the boundary. They also find it difficult to reconcile the changes in productivity with an impact because the low-productivity epidode has a duration of at least 1 million years. One possibility (Sepkoski 1984) is that the characteristic recovery time of organisms to a shocking event may be of that order of magnitude.

Alternate Extinction Mechanisms

Impact Related

Hsu (1980, 1981) noted that the dust cloud from an asteroid failed to account for selective extinctions and preferred a cometary impact. He postulated that the extinctions were due to two causes; the larger animals died in response to heat stress following the impact while calcareous plankton were done in by cyanide poisoning from the comet. Hsu *et al.* (1982) modified the scenario to include the possibility of heavy metal poisoning as well. Prinn and Fegley (1987) calculated that an asteroid coming in normal to the surface would have a modest effect on the atmosphere, but that a comet travelling through the atmosphere at grazing incidence could create enough oxides of nitrogen to produce acid rain and affect the pH of the surface ocean. The lifetime of N_2O in the atmosphere is about 150 years (Crutzen, 1987) so geologically the effect would be short term.

Both of these mechanisms respond to the selectivity problem and are more promising mechanisms than a dust cloud if a comet can produce the iridium and other effects and a crater can be found. They both have problems if the extinctions took place over a considerable span of time.

Volcanism

Numerous well documented historic eruptions have been discussed in the literature (e.g. Budyko 1977, Officer *et al.* 1986). Results of studies summarized in these publications indicate that strong positive correlations exist between volcanic emanations and reduction in temperature as well as atmospheric transparency. During volcanic eruptions CO_2 and sulphureous gases are discharged into the atmosphere; the latter reduce atmospheric transparency by increasing aerosol particles in the lower atmosphere, causing considerable air and sea-surface temperature drops (Budyko 1977). The process is followed by settling of the particles, with reestablishment of "normal transparency" and increased concentrations of CO_2, which results in rapid temperature increase.

Late Mesozoic and Early Cenozoic global volcanism was considerably more widespread than it is today (Campsie *et al.* 1984; Officer *et al.* 1987) reaching a peak in K/T time. By analogy to present day effects of volcanic activity one would expect a depression of surface water pH. Increased acidity would dissolve the calcareous shells and temporarily prohibit calcite nucleation leading to the mass mortality of the warm water calcareous phyto and zooplankton (Takahashi 1975). The dissolution of $CaCO_3$ would result in the addition of bicarbonate to the ocean water which would ultimately buffer its pH (Weyl, written communication), so for long term effects to be realized volcanic activity would have to persist, not be instantaneous.

Keith (1980, 1981) emphasized the role of volatile emissions in reducing atmospheric ozone and altering surface ocean chemistry. Ekdale and Bromley (1984) call on volcanic emissions, especially CO_2 as a possibility. Dewey McLean (1985a) suggested that the cumulative effects of CO_2 emissions over 500,000 years from the Deccan traps of India at K/T time might reduce ocean alkalinity, but this assumes that CO_2 would continue to accumulate. Feedback mechanisms over this time period, such as changes in river flux of carbon, exchanges between upper and lower ocean, changes in rates of removal in the sediments, biological activity, or others are difficult to assess and could seriously inhibit this mechanism.

Another candidate is sulphuric acid. Detrimental effects of present fossil fuel SO_2 emmission have been reported from local areas on land, but the hydrogen ion flux per unit area of the ocean from this is too small to reduce ocean pH significantly even if it all went there. However, an unusual event producing a larger amount of SO_2 over geologically short time periods of 10^2-10^5 years that was concentrated in the mixed layer of the surface ocean could have a significant effect.

The Deccan traps of India represent such an unusual event (Subbarao and Sukheswala, eds., 1981. Olmez *et al.* (1986) estimated that the iridium emission could be expected to produce about 30,000 tons, a little less than believed to be present at the K/T boundary. They were extruded at K/T time near the equator where vertical circulation of the atmosphere is strong and were handily located near the mouth of the Tethyan Sea. The remnants after erosion have a volume of at least 10^6 km^3 and the great bulk of them were extruded during one reversed magnetic interval, 29R, that spans about half a

million years and crosses the K/T boundary. Courtillot *et al.* 1986). If they were extruded evenly over this entire period, they would represent an approximate doubling of the present rate of non-ocean-rift volcanism (Nakamura 1974). If they were extruded in pulses, the short-term rate increase would be even greater.

Volcanic eruptions are, of course, intermittent (Axelrod 1981; Kennett and Thunell 1975, 1977; Kennett *et al.* 1977; Donn and Ninkovich 1980). On a historical time scale variations in volcanic energy release of two orders of magnitude are found. The Cenozoic record of sediment cores from the sea floor shows variations of the same order. Swanson (1975) estimated that the 700 km^3 Roza flow in the Miocene Columbia basalts was erupted in about a week. The idea of major volcanic pulses does not seem at all unreasonable.

Data from Laki in Iceland and Kilauea in Hawaii indicate that fissure volcanoes like the Deccan traps emit more H_2SO_4 per unit volume of ejecta than do explosive volcanoes (Devine *et al.* 1984; Sigurdsson 1982, Rose *et al.* 1985). A back of the envelope calculation suggests that intense volcanic pulses in the time frame from 10^2 to 10^4 years could produce enough acidity to make life difficult for carbonate dependent organisms; any explosive volcanism at K/T time would add to this effect. Geochemical data suggest that the CO^2 content of the Cretaceous atmosphere was higher than it is today and a further increase from volcanic CO^2 would accentuate the effects. When one adds to these emissions the mountain building, the major regression of the sea, and the climatic effects to be expected from these, it is not surprising that we now live in a dinosaur-free environment.

Conclusion?

A novel cause for global events seems to have much more popular appeal than a more pedestrian one. It is surprising how readily we can accept that the spray cans that we use to keep our bodies inoffensive and our blow-dry coiffures in place are destroying the ozone layer over Antarctica, or that the effluent from the fossil fuel we burn is killing off the trees and changing the climate, but at the same time find it difficult to believe that the extrusion of over a million cubic kilometers of lavas with their associated volatiles will have little effect on the environment. Surely if the CFCs in the spray cans can destroy the ozone layer, the volatiles (including chlorine, fluorine, carbon dioxide and sulphur dioxide) from this enormous eruptive event must have had a significant effect. Can it be just coincidence that the other major Phanerozoic eruption of the same order of magnitude occurred in Siberia at the transition between the Paleozoic and Mesozoic eras?

Extinctions are close to the heart of geology. The geological time scale was based on the comings and goings of organisms through the eons. Theories of evolution are based on the changes in organisms through time and how and why they change is crucial to these theories. Regardless of whether the impact theory is right or wrong, we should be grateful to its developers because they have stirred up a great deal of research which will move us closer to the truth.

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Present all data in international (SI) units. English equivalents may be added parenthetically. Use the 24-hour clock (0600 and 2300) and continental dating (17 November 1982).

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(Founded 1923)

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Announcements

In this Issue

Letters to the Editor

I encourage those with short comments to make on research and review articles that have appeared in *Northwest Science* to share these comments with the readership through a "Letter to the Editor." Such "Letters" should be brief and to the point. They may contribute an added note of support, extend an interpretation, offer an alternative perspective, or take issue with an article; however, undue belligerance is out of place.

The letter should be sent to the Editor, in triplicate.

—Editor

Association News

The Northwest Scientific Association was officially launched 6 April 1923. Over the years its members have had a profound effect, although largely unappreciated, on the development of agriculture, engineering, forestry, biology, and other sciences in the Northwest. As the Association has grown and its interests broadened, the early records of its activities have tended to be scattered and this history lost. A history of the Association from its founding up until 1959 was compiled by Willis B. Merriam and separately published. Merriam together with Adolph Hecht and Rufus W. Kiser assembled names and events of the Association thereafter up until 1972. This record appears under Association News in this issue.

Highlights from the Annual Meeting

The annual meeting of the Northwest Scientific Association was hosted by Southern Oregon State College, Ashland, Oregon. Eighty-six papers were presented, along with two successful symposia and three field trips. With 230 registered participants, the meetings were judged a large success by Northwest Scientific Association president, Steve Tesch and program chairman Claude Curran. Of particular interest to members are the following:

Outstanding Scientist Award

The Outstanding Scientist Award was presented by the Northwest Scientific Association to Dr. M. A. Radwan, with the USDA Forest Service PNW Research Station in Olympia, Washington, for his scientific accomplishments of outstanding importance to the Northwest.

Honorary Life Member

Honorary Life Membership was presented by the Northwest Scientific Association to Dr. Denis Lavender, present head of the Forest Sciences Department at the University of British Columbia, in recognition of service to the Association over many years.

Research Grants

Research grants in the amount of $300 were awarded to each of the following students:

Jennifer Dimling, Department of Biology, University of Oregon
David N. Lindberg, Department of Geology, Humboldt State University
Stephen P. Mackessy, Department of Zoology, Washington State University
John Megahan, Department of Marine Biology, University of Oregon
Erin Elizabeth Peters, Department of Marine Biology, University of Oregon

(Continued on page 204)

Dale E. Toweill,[1] Oregon Cooperative Wildlife Research Unit,
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Reproductive Characteristics of Eastern Oregon Cougars

Abstract

Knowledge of reproductive characteristics and reproductive rates are a critical concern to wildlife managers, but such data are difficult to obtain for free-ranging predators. In order to obtain these data, we examined the reproductive tracts of 46 male and 51 female subadult and adult cougars (*Felis concolor missoulensis*) killed by hunters during the month of December, 1976-1982. Among males, 24 (52%) showed evidence of spermatogenesis. Sexually mature males may lack sperm during a portion of the year. Of the 51 females, 23 (45%) were classified as reproductively active based on evidence of corpora lutea in ovaries or sites of embryo implantations in uteri. Corpora lutea of pregnancy appear to be short-lived. Four females (8%) were pregnant in December. Placental scars of females may be used to estimate the minimal level of fecundity in the population. Estimated mean litter size based on placental scars ($n = 10$) was 2.4 ± 1.08 kittens. These data indicate that previously published guidelines for assessing sexual maturity of cougars based on body weight may lead to erroneous conclusions. The best estimator of cougar fecundity is provided by counts of placental scars.

Introduction

Large samples of reproductive data from populations of long-lived, free-ranging predators are difficult to obtain. Few data on reproductive characteristics of cougars have been published. Most of the information available, as summarized by Anderson (1983), refers to captive animals. Descriptions of reproductive characteristics of free-ranging cougars is limited to reports by Robinette *et al.* (1961) on ovarian analysis of 33 females among a much larger sample of cougars taken by hunters and government trappers from Utah and Nevada, and by Toweill *et al.* (1984) on reproductive characteristics of 18 males and 34 females from western Oregon. We report on some reproductive characteristics of 46 male and 51 female cougars killed by hunters in northeastern Oregon during the month of December, 1976-1982.

Methods

Carcasses or reproductive tracts of cougars taken by hunters were routinely collected by personnel of the Oregon Department of Fish and Wildlife as part of a program to gain biological information on the species. Carcass weights and measurements were recorded, and reproductive tracts (testes and epididymides for males; ovaries and uteri for females) were frozen for later analysis. Reproductive tissues were later thawed, fixed in 10% formalin, and stored in 70% alcohol. One testis with attached epididymus was wax-embedded, sectioned at a thickness of 7-8 micra, stained with hematoxylin and eosin, and examined microscopically for evidence of spermatogenesis. Ovaries were sectioned grossly at a thickness of approximately 1 mm and examined under a dissecting microscope for presence of Graafian follicles, corpora lutea, and corpora albicantia. Uteri were examined for embryos and sites of previous embryo attachment (placental scars). Some uteri were cleared by progressive dehydration in alcohol and immersion in methyl salicylate to facilitate identification of placental scars.

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[2]Present address: Sustainable Forestry, 1462 N.W. Taylor, Corvallis, Oregon 97330.

Results and Discussion

Usable reproductive tracts were collected from 46 (78%) of 59 male and 51 (82%) of 62 female subadult and adult cougars killed by hunters in northeastern Oregon during the month of December, 1976-1982, under an either-sex harvest regulation. The sex ratio did not differ ($p < 0.05$) from 1:1.

Reproductive Characteristics of Males

No effort was made to separate young unspotted cougars from adults based on size or body conformation, because materials received varied from entire carcasses to reproductive tissues only. Twenty-four (52%) of 46 males examined were sexually mature based on spermatogenesis or mature sperm in the epididymides. This ratio of spermatic animals is similar to the ratio of 44 percent spermatic males in a sample of cougars (*F. c. oregonensis*) from western Oregon collected during December and January (Toweill *et al.* 1984). Data indicating the age at which primary spermatocytes first appear in male cougars is lacking (Anderson 1983). Evidence of spermatogenesis or spermatoza to identify males that were sexually mature may not have included all physically mature males in the sample. Among those that were aspermatic and which were weighed intact (n = 13) were males that weighed 59.4 and 66.2 kg, well over the arbitrary weight of 56.7 kg considered indicative of adult males by Robinette *et al.* (1961), suggesting that physically (sexually?) mature males may be aspermatic during a portion of the year. Among 21 adult males showing evidence of spermatogenesis or mature sperm in the epididymides and for which intact carcass weights were available, 19 percent (4) weighed less than 56.7 kg (47.2, 50.8, 51.5 and 53.1 kg, respectively).

Reproductive Characteristics of Females

Based on evidence of previous ovulation or sites of previous embryo implantation in the uterus, 21 (41%) of 51 females for which reproductive tracts were available were classified as reproductively active adults. Corpora albicantia could not be conclusively identified because of the presence of numerous small areas of fibrosis in active ovaries. By comparison, 14 (64%) of 22 females collected from western Oregon were classified as reproductively active by these same criteria (Toweill *et al.* 1984).

Robinette *et al.* (1961) reported that female cougars in their sample from Utah and Nevada reached sexual and physical maturity at whole-body weights of about 80 pounds (36.4 kg). Application of this criterion to 21 female cougars judged immature based on analysis of reproductive tracts and for which whole body weights were recorded ($\bar{x} = 37.4 \pm 4.2$ kg, range = 31.8 – 47.3 kg) resulted in misidentification of 10 animals (48%) as sexually mature. Conversely, application of the whole-body weight criterion to 20 cougars ($\bar{x} = 41.4 \pm 5.2$ kg, range = 31.4 to 55.5 kg) shown by examination of reproductive tracts to be sexually mature resulted in misidentification of two animals (10%). These data suggest that use of body weight alone to assess the proportion of sexually mature animals in this population would have resulted in an overestimate of 47 percent, i.e., a net error of eight animals (20% of the sample). A portion of the error results from the fact that cougars are probably induced ovulators (Bonney *et al.* 1981). If so, copulation is necessary to trigger ovulation and formation of corpora lutea in the ovaries, and sexually mature females that have not mated would therefore show inactive ovaries. Although data from captive animals indicate that female cougars may first breed as early as 17 to 18 months of age (Eaton and Velander 1977:52), age at first breeding has more typically been reported up to 28 to 29 months of age (Eaton and Velander 1977:52), 29 months (Rabb 1959), and 27, 31, and 33 months (Young 1946:214). Further, it has been inferred from field studies (Hornocker 1971) that wild female cougars probably do not breed until they have established a home area. Thus, using ovarian structures as evidence of sexual maturity may underestimate the sexually mature segment of the population, since no structures are likely to occur in nonterritorial (and therefore, not reproductively active) females. Removal of territorial females may have little effect on a population if sexually mature but nonterritorial females are available to fill vacancies created.

Using the presence or absence of ovarian or uterine structures as indicators of reproductive history must be done cautiously because the period of persistence of these structures in cougars is unknown. Cougar ovaries are histologically similar to those of both the domestic

cat (*F. domesticus*) and bobcat (*F. rufus*) (Mossman and Duke 1973), but ovarian structures associated with pregnancy in the cougar may regress much more quickly than in those species. Mossman and Duke (1973) believed that corpora lutea of cougars likely persisted about one year after parturition. However, Toweill *et al.* (1984:182) reported four instances wherein corpora lutea apparently regressed more quickly, including one instance where an adult female accompanied by two kittens (believed 6 to 10 months old based on whole-body weights of 25 kg) lacked corpora lutea although three sites of embryo implantation were identified. In each of the instances discussed by Toweill *et al.* (1984:182), and in four of the ten cougars with placental scars examined in this study, fewer corpora lutea than embryo implantation sites were found, suggesting a tendency towards more rapid regression of corpora lutea than placental scars following parturition.

Four (8%) of the females examined were pregnant when killed in December, a pregnancy rate slightly higher than that calculated for December from all other sources by Anderson (1983:32). In each case, number of embryos and placental scars was equal. Placental scars only were found in the uteri of six (12%) of the females examined. Based on placental scars, an estimated litter size of 2.4 $\pm$ 1.08 (range 1 to 4) kittens was derived, similar to the mean litter size of 2.8 kittens ($n=11$) calculated by similar methods for western Oregon cougars (Toweill *et al.* 1984:181). However, both values are lower than the average of 3.32 $\pm$ 1.02 kittens in prenatal litters as calculated by Anderson (1983:34) from a wide range of sources.

Management Implications

Often the only way to assess the productivity of mammalian populations is to determine the proportion of reproductively active animals in a representative sample. Data obtained during this and a companion study (Toweill *et al.* 1984) suggest that analysis of the reproductive tracts of female cougars obtained by hunters can be used cautiously to interpret the minimal prior-year fecundity in a cougar population. More knowledge of the temporal relationship between persistence of corpora lutea of pregnancy and placental scars is needed.

The ability to assess recent fecundity is extremely important as cougar management plans are considered, but simple generalizations are difficult to apply since adult female cougars may produce litters during any month of the year (Robinette *et al.* 1961) and at intervals ranging from $<$ 12 (Eaton and Velander 1977:65) to $\geq$ 24 months (Robinette *et al.* 1961, Hornocker 1970). Because placental scars may persist longer than corpora lutea of pregnancy, counts of placental scars may be the best estimator of prenatal litter sizes and pregnancy rates.

Acknowledgements

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Spotted Knapweed in Natural Area Fescue Grasslands: An Ecological Assessment

Abstract

Spotted knapweed (*Centaurea maculosa*) is an introduced species to the Pacific Northwest, and competitor with native species. This study assessed 1) the capability of spotted knapweed to invade fescue grasslands in Glacier National Park (USA) and 2) the effects of spotted knapweed on these indigenous communities. Transects were established in roadside areas and adjoining grassland communities on three sites from 1984-87. Spotted knapweed stem densities, the occurrence of associated species, and spotted knapweed seed production were observed within quadrats along these transects. Seed production in roadside areas was relatively high, presumably facilitating knapweed invasion into adjacent grassland vegetation. Stem densities in transects along the outer areas of each colony increased significantly during the study, suggesting that spotted knapweed is capable of successfully expanding within the park's fescue grasslands. Species richness and the frequency of several species were inversely related to spotted knapweed stem density, suggesting that spotted knapweed invasion is capable of altering plant community composition. Though these trends should be evaluated over a longer time span and in other areas, there seems to be sufficient reason for concerrn about spotted knapweed's disruptive potential in natural area grassland communities in this region.

Introduction

Spotted knapweed (Asteraceae: *Centaurea maculosa* Lam.) is an Eurasian species common in a number of rangeland areas of the Pacific Northwest. It apparently was introduced into this region around 1900 and now occupies over 800,000 ha in Montana alone (French and Lacey 1983). Reported negative effects exerted by spotted knapweed and a closely related species, diffuse knapweed (*C. diffusa*), include allelopathic suppression of seed germination and seedling growth (Fletcher and Renney 1963, Muir and Majak 1983, Kelsey and Locken 1987, but see also Locken and Kelsey 1987), reduced forage yield (Watson and Renney 1974, Myers and Berube 1983), and possible increased soil erosion from displacement of perennial grasses (French and Lacey 1983).

Spotted knapweed is capable of vegetative reproduction, though lateral shoots do not become detached from the parent root stock (Watson and Renney 1974). Colony expansion is thus dependent on seed dispersal and is facilitated by substrate disturbance and excessive livestock grazing (Watson and Renney 1974, French and Lacey 1983). As is the case for other alien species in western Montana (Forcella and Harvey 1983), roadside habitats appear to be especially suitable for spotted knapweed colonization (French and Lacey 1983; Tyser, personal observation).

Spotted knapweed is usually studied from an agricultural perspective (e.g., Watson and Renney 1974, Shirman 1981, Myers and Berube 1983). There is reason, however, to be concerned about its occurrence in natural area grasslands, that is, grasslands protected from agricultural use and significant human disturbance (Weaver and Woods 1985). Invasion of diffuse knapweed may be reduced in areas seeded with grass (e.g. *Agropyron cristatum*), though the extent of this reduction appears to be affected by grass species and precipitation (Berube and Myers 1982). These observations raise the possibility that natural area grassland communities, if not disturbed by humans or livestock, may successfully resist spotted knapweed invasion.

The present study considers the invasive potential of spotted knapweed in grasslands dominated by *Festuca scabrella* and *F. idahoensis* in the St. Mary area of Glacier National Park, USA. Prior to establishment of Going-to-the-Sun Highway in the mid-1930's, these areas were likely subjected to some degree of grazing from pack

horses used in touring the park. Trespassing livestock, primarily cattle, are occasionally sighted in these grasslands, but apparently exert minimal impact (Clifton 1977). Because of limited livestock grazing and restricted human-related substrate disturbance (e.g. road and trail construction), these grasslands have been subjected to relatively little human disturbance since the park was established in 1910.

Spotted knapweed was first observed in the park in the mid-1960's (R. Wassem, personal communication). It is now widely distributed in the park, but is primarily restricted to roadside areas. In several locations, however, spotted knapweed colonies have expanded from the roadside into the edge of adjacent fescue grasslands (Weaver and Woods 1985; Tyser, personal observation). While no federally listed rare, threatened, or endangered species are known to occur in these grasslands (Lesica *et al.* 1984), the ultimate esthetic and biological impact of spotted knapweed on these areas is a legitimate concern.

This investigation, which examined several locations where spotted knapweed occurred in the grassland-roadside ecotone, had two primary objectives: 1) to determine if spotted knapweed is capable of significant dispersal into Glacier's natural area fescue grasslands, and 2) to assess the potential effects that spotted knapweed has on the plant community composition of these grasslands.

Methods

Study Sites

Three sites were studied in Glacier National Park from 1984-87. Each of the sites was in Glacier's St. Mary valley region and consisted of spotted knapweed stands grading into grasslands dominated by native fescue species (*Festuca idahoensis* and *F. scabrella*). These grasslands are classified as short grass prairies (Kaul 1986) and are representative of the *F. scabrella/F. idahoensis* habitat type of Mueggler and Stewart (1980). Timothy (*Phleum pratense*), an alien Eurasian species, is widely distributed throughout the grasslands in this region and was common in each study site. Mean annual precipitation in this area is approximately 65 cm (Finklin 1986).

In two sites, the Triple Divide turnout ("TDT") and Two Dog Flats ("TDF") sites, spotted knapweed had dispersed about 10-20 m from the roadside ditch into grasslands bordering Going-to-the-Sun Highway. The sites were located about 5.5 km and 3.0 km, respectively, southwest of the St. Mary entrance station. With the exception of the roadside ditch bordering these sites and some substrate slumping associated with the roadbed cut in the TDT site, no human-related substrate disturbance was evident in either site. In addition to *Phleum pratense,* four relatively uncommon alien species (*Cirsium arvense, Poa pratensis, Taraxacum officinale,* and *Tragopogon dubius*) also occurred in the TDF site. The third site ("STM"), located approximately 0.5 km east of the St. Mary entrance station, was adjacent to the intersection of an access road with Going-to-the-Sun Highway. The substrate in the central part of this site had been disturbed by sewer line construction in 1980 (J. Vekasy, personal communication).

Sampling Procedures

Transects (40-50 m in length) were placed in three locations within each site: 1) in the center of the spotted knapweed colony ("core" transects), 2) 1-2 m immediately inside the colony perimeter ("fringe" transects), and 3) parallel to the fringe transect along the perimeter of the colony ("perimeter" transects). Permanent stakes allowed consistent placement of transects within each site from year to year. In addition, roadside transects were established between the core transect and the road in the TDT and in TDF sites. Spotted knapweed stem densities were determined each year in 20 x 50 cm (0.1 m^2) quadrats placed at 0.5 or 1.0 m intervals along these transects. Because multiple stems may be produced from the root crown of a single spotted knapweed genet (Watson and Renney 1974), stem density can not be considered as an estimator of population density.

Spotted knapweed stems were collected along the roadside and core transects at the TDF site in late August in 1984 and 1985 and at TDT site in 1985. Collections were made after flowering was completed, but before opening of seed head bracts. Estimates of seed production densities along these transects were calculated by multiplying stem density x seed heads/stem x seeds/seed head (Schirman 1981).

The occurrence of vascular species (excluding *Carex* spp.) was noted in the core, fringe, and perimeter quadrats at the TDF site, but not at the TDT or STM sites. Frequencies of individual species, defined as the percent of quadrats in which a species was observed, were determined each year. Species frequency categories were designated as follows: common species (species occurring in > 50 percent of the quadrats), uncommon species (species occurring in 5-50 percent of the quadrats, and rare species (species occurring in < 5 percent of the quadrats). Species nomenclature follows Hitchcock and Cronquist (1973).

In 1987 the percent surface area of recently disturbed soil (loose, unvegetated soil) was estimated along each transect in the three study sites. Presence or absence of recently disturbed soil was noted at three points at 0.5 m intervals: one point on each 0.5 m transect mark and two points 0.25 m perpendicular to each 0.5 m mark.

Statistical Analysis

Linear regression slopes were calculated and statistically evaluated to assess 1) yearly trends in spotted knapweed stem densities at each site, 2) yearly trends in species richness at the TDF site, and 3) the relationship between spotted knapweed stem density and number of non-knapweed species per quadrat at the TDF site. Stem densities in a number of transects were non-normally distributed and could not be transformed by standard logarithmic or square root transformations. Therefore, stem densities were rank-transformed and the ranks were evaluated by linear regression (Conover and Iman 1981).

Two-way analysis of variance was used to analyze species richness patterns with respect to two factors: transect location (three levels: core, fringe and perimeter) and year (four levels). The Newman-Keuls test was used to determine differences between the means of each level for each factor found to be significant (Zar 1984). Core versus perimeter frequencies of individual species were compared using 2 x 2 contingency tables analyzed with the Fisher exact test. This test was used rather than the chi-square or the G-test because it is preferable when cell frequencies are small (Zar 1984: 65), which was the case for a number of species. Between transect differences in number of points hitting disturbed soil were compared using chi-square.

Results

Stem Densities

Spotted knapweed densities increased significantly from 1984-87 in each of the fringe and perimeter transects at the three study sites (Figure 1). Even in the colony core areas, where knapweed stem densities were highest and presumably closest to equilibrium levels, densities increased in two of the three study sites (the TDT and STM sites). Spotted knapweed colony fronts at the study sites advanced less than 10 m during the study. However, it is likely that seed dispersal exceeded this distance.

The mean stem densities in the colony core areas for the TDT, TDF, and STM knapweed colonies in 1987 were 7.1, 7.6, and 6.6 stems/0.1 m^2, respectively. Though it is difficult to predict what density spotted knapweed is capable of attaining in these grasslands, these data suggest that equilibrium stem densities exceed 7.0 stems/0.1 m^2.

Seed Production Estimates

Seed production estimates from stems collected along the core and roadside transects at the TDF site in 1984 and 1985 are summarized in Table 1. Unmowed roadside knapweed plants were notably larger and produced more seed heads per stem compared to mowed plants. However, after mowing in June 1985, spotted knapweed plants produced an increased number of relatively small lateral stems which offset the fewer number of seed heads per stem (Table 1). As a result, calculated seed production along the roadside transect was fairly constant in both years, and was significantly higher than that along the core transect. Similar results were noted at the TDT site, where seed production in 1985 was calculated as 881 and 2,471 seeds/0.1 m^2 in the core and roadside quadrats, respectively.

Species Richness Observations (TDF Site)

Species richness patterns at TDF showed significant between-transect and between-year differences (Table 2). Transect species richness means differ significantly from one another (perimeter > fringe > core; Newman-Keuls test, $p < 0.05$), indicating the presence of a spatial species richness gradient which is inversely related

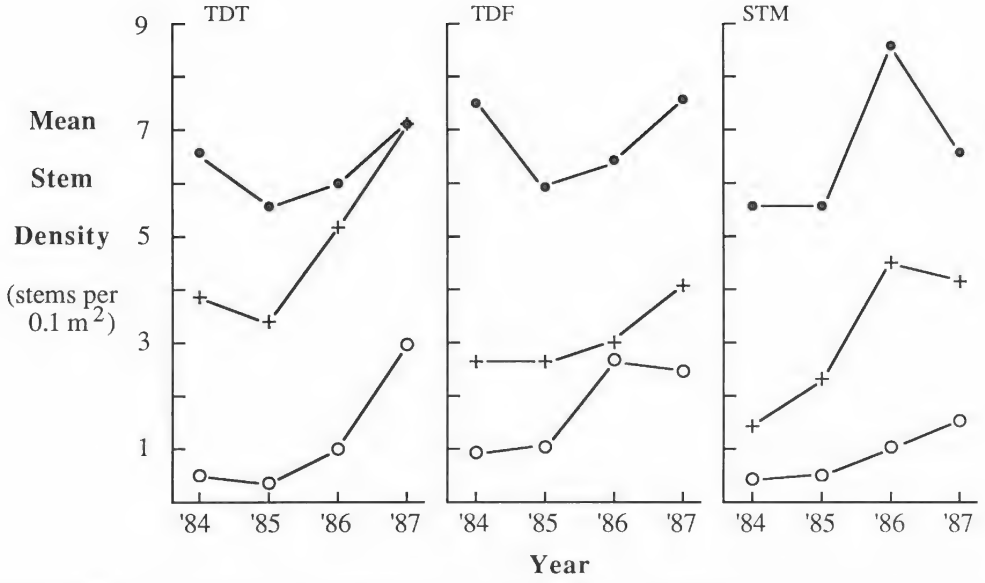

Figure 1. Trends in spotted knapweed stem densities in the core (•), fringe (+), and perimeter (o) transects in the three study sites (TDT, TDF, STM). With the exception of the TDF core transect, stem densities increased significantly (linear regression slopes $\neq 0.0$, $p < 0.05$) along each transect from 1984-87.

TABLE 1. Comparison of spotted knapweed seed production in the core area of the Two Dog Flats site versus the adjacent roadside. Number of observations—seed heads dissected, stems collected, and quadrats examined—are indicated in parentheses.

	Core Area		Roadside	
	1984	1985	1984	1985[a]
$\bar{X}$ seeds/seed head	23.5 (106)	29.1 (144)	25.4 (364)	28.5 (309)
$\bar{X}$ seed heads/stem	4.8 (51)	4.7 (50)	16.9 (51)	5.2 (50)
$\bar{X}$ stems/0.1 m^2	5.6 (41)	5.9 (41)	8.7 (41)	16.0 (41)
Calculated seeds/0.1 m^2	846	806	3,734	2,629

[a]Transect mowed in June 1985

TABLE 2. Species richness (mean number of species—excluding spotted knapweed and *Carex* spp.—per 0.1 m^2 quadrat) patterns in the TDF knapweed colony. Species richness varied significantly with respect to both location and year (two-way ANOVA, $p < 0.05$).

Transect Location	1984	1985	1986	1987	Transect Mean	Number of Quadrats
Core	6.5	6.9	6.3	6.4	6.5	41
Fringe	7.6	8.1	7.3	7.0	7.5	46
Perimeter	8.6	8.9	8.4	8.3	8.6	50
Yearly Mean	7.7	8.0	7.4	7.3		

to spotted knapweed stem density. In addition, linear regression using the 1987 TDF observations indicated a highly significant negative relationship between knapweed stem density and number of non-knapweed species per quadrat: $y = 8.01 - 0.16x$, where y = number of non-knapweed species/quadrat and x = number of spotted knapweed stems/quadrat (slope $\neq 0.0$, $t_{135df} = 4.526$, $p < 0.001$). Except for the clear association with spotted knapweed stem densities, no other prominent environmental correlate appeared to be associated with this species richness gradient. For example, no significant between-transect differences in substrate disturbance were observed (see below).

Comparable analysis of the differences in yearly species richness means show less prominent patterns, though 1985 values were significantly higher than the 1984 and 1986-87 values (Newman-Keuls test, $p<0.05$). In addition, regression analyses suggest that no significant changes in species richness occurred within either the core or perimeter quadrats from 1984-87. However, a small, but significant, decline in species richness occurred in the fringe quadrats (regression slope = -0.28, $t_{182df} = 2.073$, $p < 0.05$) during this period.

Species Frequency Patterns (TDF Site)

Alien Species. Spotted knapweed frequencies were relatively high at the TDF site, with mean yearly frequencies of 99.4, 82.6, and 74.0 percent in the core, fringe and perimeter quadrats, respectively. In addition to spotted knapweed, three other alien species (*Phleum pratense, Poa pratensis,* and *Tragopogon dubius*) were observed in the TDF quadrats. Mean yearly frequencies of *P. pratensis* and *T. dubius* were relatively low (*P. pratensis:* 11.6, 0.5, and 6.0 percent, *T. dubius*: 0.6, 5.4, and 6.5 percent for the core, fringe, and perimeter transects, respectively). Mean yearly frequencies of *P. pratense* were relatively high (68.3, 85.9, and 82.5 percent for the core, fringe, and perimeter transects, respectively).

Frequency Patterns in the Fringe Transect. Comparison of 1984 and 1987 fringe transect frequencies (Figure 2) reveals changes associated with the species richness decline noted earlier for this transect. Of the 38 species observed in the fringe quadrats in 1984, 31 were reclassified at the same frequency level in 1987. However, 7 of the original 38 species were reclassified into lower frequency categories in 1987 (*Galium boreale, Hieracium umbellatum, Potentilla*

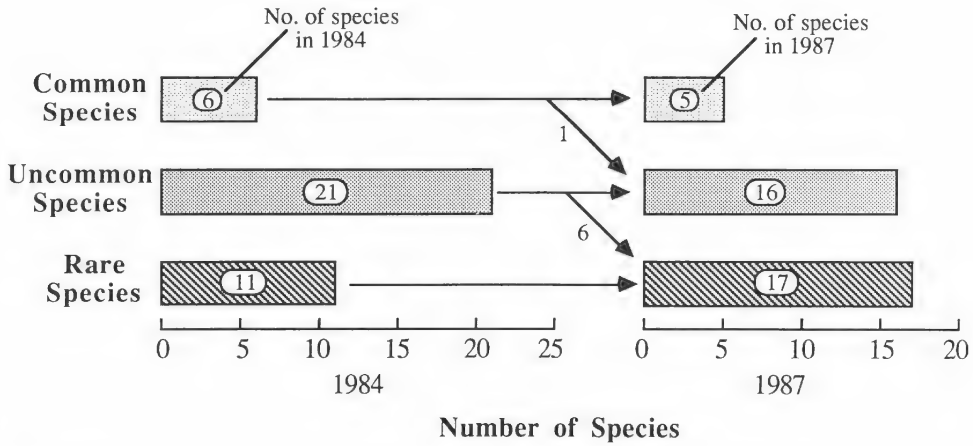

Figure 2. Number of species in three frequency categories in the 1984 versus 1987 fringe transect. Of the seven frequency category changes which occurred, each was from a higher to a lower category. For example, of the 21 species classified as "uncommon" in 1984, six were reclassified as "rare" in 1987. (Common, uncommon, and rare species occurred in >50%, 5-50%, and <5%, respectively, of the fringe quadrats.)

arguta, Potentilla gracilis, Silene parryi, Stipa occidentalis, and *Tragopogon dubius*). No species were reclassified into higher frequency classes.

In addition, five "rare" species (*Agropyron spicatum, Castilleja cusickii, Collomia linearis, Heuchera cylindrica,* and *Lithospermum ruderale*) and two "uncommon" species seen in 1984 (*Stipa occidentalis* and *Tragopogon dubius*) were not observed in any of the fringe quadrats in 1987. By comparison, only one species (*Poa pratensis*) was observed in the fringe quadrats in 1987 which was not observed in 1984. Thus, the decline in species richness which occurred in the fringe area of the TDF knapweed colony is consistent with changes observed in frequencies of individual species.

Core versus Perimeter Frequency Comparisons. If spotted knapweed affects native species, the frequencies of affected species may differ between quadrats with high knapweed stem densities (core quadrats) and quadrats with low knapweed stem densities (perimeter quadrats). Core versus perimeter comparisons at the TDF site indicate that frequencies of four to seven native species showed significant differences each year (Table 3).

In all but three instances (*Berberis repens* in 1984 and 1985, and *Rosa* spp. in 1984), species showing significant differences were more frequent in the perimeter transect than the core transect. Interestingly, in two instances the frequencies of alien species (*Tragopogon dubius* in 1984 and *Phleum pratense* in 1986) were significantly higher in the perimeter quadrats than in the core quadrats, suggesting that spotted knapweed may also negatively affect the distribution of other alien species.

Only two of the species listed in Table 3, *Festuca idahoensis* and *Phleum pratense,* were common (frequency $>50\%$) in the perimeter transect during each year of the study. Hence, most of the differences summarized in Table 3 pertain to species which were either uncommon or rare. Four other species (*Achillea millefolium, Cerastium arvense, Festuca scabrella,* and *Galium boreale*) were also common in the perimeter transect. With the exception of *Galium boreale* in 1987, frequencies of each of these species were higher in the perimeter transect than in the core transect, though these differences were not significant (Fisher exact test, $p>0.05$).

Substrate Disturbance Observations

A significant proportion of substrate surface consisted of recently disturbed soil at each site. The percent coverage of disturbed soil was quite similar along each transect at the TDF site (9.4, 8.2, and 7.8 percent for the core, fringe, and perimeter transects, respectively) and showed no significant between-transect differences ($\chi^2_{2df}=0.47$, $p>0.75$). Corresponding observations at the other two sites were 20.4, 8.7, and 9.6 percent (TDT site), and 4.2, 11.1, and 5.0 percent (STM site). The relatively large proportion of disturbed soil in the TDT core area apparently resulted from slumping associated with the roadbed cut. Otherwise, recent soil disturbance in the three sites resulted from occasional Columbian

TABLE 3. Year-by-year listing of species showing significantly different (Fisher exact test, $p<0.05$) core versus perimeter frequencies at the TDF site. The species listed represent 9.5 – 16.7% of the total number of species observed per year in the two transects. Except as indicated,[a] the frequency of each species was higher in perimeter quadrats than in core quadrats.

1984	1985	1986	1987
Berberis repens[a]	*Berberis repens*[a]	*Agoseris glauca*	*Festuca idahoensis*
Campanula rotundifolia	*Festuca idahoensis*	*Lupinus sericeus*	*Koeleria cristata*
Festuca idahoensis	*Gaillardia aristata*	*Festuca idahoensis*	*Lupinus sericeus*
Gaillardia aristata	*Koeleria cristata*	*Phleum pratense*	*Solidago missouriensis*
Lupinus sericeus	*Lupinus sericeus*	*Potentilla gracilis*	
Rosa spp.[a]	*Stipa occidentalis*		
Tragopogon dubius	*Lomatium triternatum*		

ground squirrel (*Spermophilus columbianus*) burrow diggings and other disturbances, presumably from ground squirrel or wintering elk foraging activities. Old, apparently abandoned, Columbian ground squirrel and badger (*Taxidea taxus*) burrows were also present at the study sites. In several instances, relatively high spotted knapweed stem densities occurred on excavations associated with these burrows.

In addition, two small isolated spotted knapweed stands were observed on ground squirrel burrow mounds at the TDF site which were >100 m from the nearest knapweed colony. It is possible that these disjunct colonies resulted from seed heads transported by Columbian ground squirrels (see also Mittelbach and Gross 1984).

Discussion

This study suggests that spotted knapweed in Glacier National Park is capable of i) colonizing fescue grasslands adjacent to roadside knapweed populations, and ii) subsequent dispersal within these grasslands. Roadside populations appear to have relatively high levels of seed production (Table 1 and Schirman 1981), which presumably facilitates grassland colonization. Post-colonization dispersal of spotted knapweed within these grasslands may be characterized as a gradual, broad, frontal expansion along colony borders. Seedfall for this species occurs within 1 m of the parent plant, whereas diffuse knapweed plants break off at ground level and disperse seeds in a "tumble-weed" manner (Watson and Renney 1974). These differences in seed dispersal probably account for the relatively slow, gradual colony expansion noted for spotted knapweed in this study compared to the approximately 40 m/year rate of advance by diffuse knapweed observed by Myers and Berube (1983). However, animal-aided long-distance seed dispersal and subsequent establishment of disjunct spotted knapweed colonies appear to also occur.

The increase in spotted knapweed stem densities in the TDF fringe quadrats coincided with a decline in the frequency of some species (Figure 2) and a small, but significant decline in species richness in the same quadrats. These trends were consistent with a number of other observations, including the between-transect spatial patterns of species richness noted in Table 2, and the perimeter versus core frequency differences of various common and less common species summarized in Table 3. Parallel patterns were also observed in another grassland site studied in Glacier composed largely of *Agropyron caninum* and *Poa* spp. (Tyser, personal observation). While it is likely that additional contributing factors may exist, these observations strongly suggest that spotted knapweed is capable of altering the community composition of Glacier's fescue grasslands.

Although a number of significant questions remain (e.g., to what extent will spotted knapweed's expansion continue?), it is useful to consider what factors may contribute to spotted knapweed's apparent success in Glacier's fescue grasslands. One component of this success is spotted knapweed's presence in the park's roadside areas, which appears to precede dispersal into adjacent grasslands. Exotics are often well-represented in roadside plant communities (Frankel 1970, Forcella and Harvey 1983), including roadsides in natural areas such as Glacier and Teton National Parks (Weaver and Woods 1985, 1986). As with other exotics, spotted knapweed establishment appears to be facilitated by vehicle traffic and soil disturbance (Watson and Renney 1974, French and Lacey 1983) associated with road construction and maintenance activities.

Abiotic features intrinsic to grassland ecosystems may represent another component of spotted knapweed's apparent success in Glacier. Grasslands consist of open areas having frequent breaks in cover with relatively warm-dry climates. These climatic factors appear to facilitate invasion of a number of alien species introduced into North America (Lindsay 1955, Forcella and Harvey 1983, Weaver and Woods 1985, Baker 1986, Mooney *et al.* 1986), which are likely preadapted to these conditions (see also Mack 1986).

Natural biotic features characteristic of native grasslands may also facilitate alien dispersal into Glacier's grasslands. For example, mammal (e.g., *Spermophilus*) burrowing activities create microhabitats suitable for spotted knapweed colonization, and subsequent foraging activities appear to disperse knapweed seeds to such microhabitats. Native ungulates represent another possible contributing factor. Overgrazing by wintering elk (*Cervus elaphus*), which are reaching historically high levels in the park's

St. Mary valley grasslands (Martinka 1982 and personal communication), may reduce the competitive ability of native grassland species by selectively feeding on these species. Seeds or seed heads lodged in the fur of ungulates may also facilitate the dispersal of alien species.

In addition to the presence of such biotic factors, the obvious *absence* of other biotic factors (parasites, pathogens, etc.) likely contributes to the success of alien species such as spotted knapweed. Although concern about the introduction of biocontrol agents into North American natural areas is understandable, initial attempts at spotted knapweed biocontrol have met with some success (Harris 1980, Story and Nowierski 1984). Such introductions may reduce the competitive effectiveness of aliens such as spotted knapweed, thereby enhancing populations of indigenous species.

Because other natural area grasslands in this region are characterized by many of these biotic and abiotic features, it is reasonable to suspect that they may also be vulnerable to invasion by spotted knapweed. Few similar studies of natural area grasslands are available; however, spotted knapweed stem densities (5.1-5.9 stems/0.1 m^2) and seed production densities (ca. 880-960/0.1 m^2) reported for "ungrazed rangeland" in northern Idaho (Schirman 1981: site 11) are similar to those observed in the core areas in this study. Schirman's site, dominated by *Festuca idahoensis,* was located in a state park which had not been significantly disturbed for >30 years prior to his observations (Schirman, personal communication).

The rather short term nature of this present study (four years) and the general lack of comparable studies prohibit definitive conclusions, but there seems to be sufficient reason for concern about the potential effects of spotted knapweed in natural area grasslands of this region. While spotted knapweed control actions may raise legitimate concerns about potential disruption of native communities, we offer several general comments about management of spotted knapweed in natural areas.

Because establishment of this species appears to be commonly associated with human-related substrate disturbances (e.g., road construction and maintenance, laying underground cables, etc.), natural area managers should minimize the extent to which these disturbances are allowed to occur. In the event of such disturbances, we suggest using construction materials free of knapweed seed, encouraging rapid establishment of native plant cover, and immediate follow-up treatment of colonizing knapweed plants.

If spotted knapweed is already established in roadside areas or in native communities, various ongoing integrated management actions aimed at minimizing seed production (mowing, introduction of *Urophora* gall flies and other biocontrol agents, herbicide treatment, etc.) should be carefully considered. Mowing after bud formation but prior to seed production may be an effective method of reducing seed production. Studies by Harris (1980) show that *Urophora affinis* and *Urophora quadrifasciata* gall flies may also be helpful in reducing seed production, though not in reducing established spotted knapweed populations (Schirman 1981). Lacey *et al.* (1986) offer useful suggestions about herbicide control strategies.

In formulating management actions, natural area managers should consider key natural history features of spotted knapweed, including seed and pre-flowering rosette stage longevities. Ongoing observations of marked plants (Tyser, personal observation) suggest that spotted knapweed rosettes in this region are capable of persisting four years or longer before developing their initial floral stalk (see also Boggs and Story 1987). Studies of spotted knapweed seed longevity (Chicoine and Fay 1984; Fay, personal communication) suggest that seeds of this species can persist in excess of six years in the soil. We know of no observations of how mowing influences spotted knapweed mortality, but suspect the life span of mowed plants is multi-yeared. Each of these observations suggests that a successful spotted knapweed control strategy necessitates a sustained, site-specific commitment extending over a number of years.

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Reproduction of Rocky Mountain Bighorn Sheep (*Ovis c. canadensis*) in Washington: Birth Dates, Yearling Ram Reproduction and Neonatal Diseases

Abstract

Rocky Mountain bighorn sheep (*Ovis c. canadensis*) inhabited Washington state until the mid 1930's when all wild bighorn sheep became extinct. Re-introduction began in 1972, but basic comparative data are lacking on their reproductive success and diseases affecting survival. Birth dates of *O. c. canadensis* were determined from lambs of ewes bred in the wild in northeastern Washington and from lambs of ewes bred in captivity. Six lambs from ewes bred in the wild were born during 19 May-3 June, 1986. Ten lambs from ewes bred in captivity were born during 19 May-24 June, 1987. A yearling ram sired at least five of ten lambs in captivity. Birth weights of 15 newborn lambs averaged 4.9 kg (range, 3.1 kg - 5.9 kg).

During the second year, four of ten lambs, including the last three born, died within six days after birth. Septicemia due to *Escherichia coli* caused the deaths. Accumulation of bacteria in the sheep enclosure following the initial births may have contributed to the deaths. These data indicate potential disease problems in neonatal lambs, as well as newborn lamb weights and lambing dates in Washington.

Introduction

Rocky Mountain bighorn sheep (*Ovis c. canadensis*), were extirpated from Washington state by about 1935 (Buechner 1960, Johnson 1983). The loss is attributed largely to diseases and habitat loss due to domestic livestock grazing within bighorn range. It has been speculated that bacteria commonly carried by domestic sheep are transmitted to bighorns and cause acute mortality from bacterial invasion of the lungs when the two species have close contact (Foreyt and Jessup 1982). Rocky Mountain bighorn sheep were reintroduced to northeastern Washington in 1972 when 18 sheep from Alberta, Canada, were transplanted to Hall Mountain in Pend Oreille County. Subsequently, sheep have been transplanted to other areas of the state from the increasing population at Hall Mountain (Johnson 1983). Lambing dates and breeding synchrony for bighorn sheep in Washington have not been reported.

The purpose of this paper is to report lambing dates of *O. c. canadensis* in Washington, the potential for yearling ram breeding, and the neonatal mortality of lambs born in captivity.

Methods

Twelve bighorn sheep, 11 ewes and one ram-lamb were captured in a corral trap from the herd at Hall Mountain (48°50'N,117°15W, altitude 1867m) on 19 December, 1985. Ewes in this group were between 0.5 and 8.5 years of age (mean 3.6). Seven of the ewes were two years or older and were considered to be pregnant based on their age and the date of capture. All the sheep were tagged with large, numbered colored ear markers, and they were transported by truck to a 2-ha enclosure on the Washington State University campus, Pullman, Washington (46°44'N, 117°11'W, altitude 765m). The sheep were maintained as a breeding herd and were handled only for routine preventative medicine procedures.

The pen had 2.5-m high chain link fencing and contained a 5m x 3m covered shelter that was open on three sides. Mineralized salt, alfalfa hay, and a pelleted feed (alfalfa—69%, barley—31%) were available at all times.

Ewes were observed daily and their lambing dates were recorded in 1986 (Year 1) and 1987 (Year 2). On the day of birth, the lambs were eartagged, and sex and weights were determined. Ewes in year 1 of the study were bred in the wild at Hall Mountain prior to capture. Ewes in year 2 were bred in captivity by one of two rams: a yearling ram, which was the lone male in the enclosure from the initial transport until 21 December 1986; and a mature ram, which was captured at Hall Mountain on 22 December, 1986 and placed in the enclosure that day. To determine which ram sired each lamb, approximate breeding dates were established by subtracting

the gestation period of 170-180 days (Johnson 1983) from the date of birth. If the extrapolated breeding date was on or before 21 December, it was inferred that the yearling had sired the lamb.

In year 2, lambs were weighed and ear-tagged on their days of birth. Each newborn lamb was given 1 ml Bo-Se (vitamin E and selenium) intramuscularly and the navel was dipped in iodine. Lambs that died were submitted to the Washington Animal Disease Diagnostic Laboratory (WADDL), Pullman, Washington, for necropsy.

Results

Six lambs were born in year 1 between 19 May and 3 June, a 16-day period (Table 1). Lamb 1 died of pneumonia two days after birth; the others remained healthy. Ten lambs were born in year 2 between 31 May and 24 June, a 23-day period (Table 2). Four lambs died within six days after birth; the others remained healthy. Birth weights of 15 newborn lambs averaged 4.9 kg (range 3.1-5.9).

TABLE 1. Birth dates, sexes and weights (taken within 24 hours of birth) of lambs born in year 1 (1986) from ewes that were bred in the wild.

Lamb No.	Date lambed	Sex	Weight (kg)
1.	May 19	M	unknown
2.	May 21	M	5.0
3.	May 28	F	5.0
4.	May 28	F	5.0
5.	May 31	F	5.1
6.	June 3	F	5.0

TABLE 2. Birth dates, sexes and weights (taken within 24 hours of birth) of lambs born in year 2 (1987) from ewes that bred in captivity.

Lamb No.	Date lambed	No. of Days from Dec. 22 to birth	Sex	Weight (kg)	Date of Death
1.	May 31	161	F	5.1	———
2.	May 31	161	F	5.2	———
3.	May 31	161	M	5.9	———
4.	June 1	162	F	4.3	———
5.	June 8	169	M	5.2	June 14
6.	June 11	172	M	4.6	———
7.	June 11	172	M	5.7	———
8.	June 15	176	M	3.1	June 18
9.	June 18	179	M	4.9	June 23
10.	June 24	185	F	4.8	June 25

Mature ram was placed with ewes on 22 December, 1986. Normal gestation is 170-180 days.

The four dead lambs from year 2 (lambs 5, 8, 9, and 10) were submitted to WADDL for necropsy. Their average weight, 4.5 kg, did not differ significantly (t test, $P > 0.05$) from the average for surviving lambs, 5.1 kg (Table 2). All were healthy and vigorous at birth but, within 24-48 hours, the four became lethargic, weak, began losing weight, developed diarrhea and became dehydrated. At necropsy the bacterium *Escherichia coli* was isolated from the intestine of all four lambs, and from the lungs of lambs 5 and 8. In addition, lamb 5 had severe lymphocytic depletion, low selenium levels, and *Klebsiella* spp. was recovered from the lungs. Infectious bovine rhinotracheitis virus (IBR) was isolated from feces of lamb 8. Approximately two hours prior to death, lamb 8 was treated with an oral electrolyte and glucose solution. There was no response to the treatment. Lamb 9 had marginal selenium blood levels when compared to domestic sheep and was positive for *E. coli* F41 pilus antigen from the intestine. This lamb was treated with gentocin, banamine, penicillin and oral electrolytes one day before death, but there was no positive change in condition. *Pasteurella haemolytica* was isolated from the lungs of lamb 10, but gross or microscopic lung lesions did not indicate active infection.

The yearling ram sired at least five lambs, the mature ram at least one (Table 2). Lambs 1 through 5 were sired by the yearling ram, while lamb 10 was sired by the mature ram. Four lambs, lambs 6, 7, 8, and 9, could have been sired by either ram since the gestation period overlaps the time both rams were with the ewes.

Discussion

Lambs born in year 1 from ewes bred in the wild provided valid birth dates for bighorns in northeastern Washington in 1986. Lambing dates recorded for both years appear to be late for this region, particularly the year 2 lambs. In year 2, this may have been due to the inexperience or lack of aggression of the yearling ram. In Washington, most lambs are born in early May, with the peak of lambing about May 5 (Johnson 1983). In southern British Columbia, California bighorns lamb between late April and mid-June (Geist 1971). Thorne *et al.* (1979) found that peak lambing periods of Rocky Mountain bighorn sheep in Wyoming may vary from year-to-year

within herds and between herds in one year. The lambing period of Rocky Mountain bighorns generally spans about seven weeks (Johnson 1983, Geist 1971), and is generally later and shorter in higher latitudes and elevations (Thompson and Turner 1982). The lambing period for year 1 in this study was slightly more than two weeks (n = 6) and for year 2 was just over three weeks (n = 10).

Birth weights of 15 newborn lambs ranged from 3.1 kg to 5.9 kg, (x = 4.9 kg) (n = 15). This is compatible with other reported captive bighorn lamb birth weights which ranged from 2.8 to 5.5 kg (Bunnell 1982, n = 17). Geist (1971) surmised that 5.0 - 5.5 kg would be the maximum birth weight for bighorn sheep. Eight lambs from this study fell within this range and two exceeded the upper limit.

Potential problems with survival of captive bighorn lambs is illustrated in year 2. Four of ten lambs born that year died soon after birth. All ten lambs appeared equally healthy and active at birth. Bacterial accumulation in the enclosure may have contributed to the deaths by overwhelming the passive immunity of the lambs. The bacterium *E. coli* was isolated from all dead lambs, and bacterial septicemia was the major factor in the deaths. Colibacillosis, caused by *E. coli,* is a major cause of death in calves and domestic lambs under ten days of age (Blood *et al.* 1983). This disease is especially common on farms where crowded calving or lambing occurs. One of the lambs also was positive for IBR virus. (IBR is a herpes virus generally found in cattle and known to cause abortions.) Apparently this is a first report of IBR in bighorn sheep. The significance of IBR in bighorns is unknown, but did not appear to be responsible for illness or death in the lamb.

To prevent neonatal mortality associated with bacterial infection in captive bighorn lambs, I recommend larger pens for captive ewes during the lambing period which would allow for some degree of isolation of lambs from feces, or placing fewer ewes in each pen to reduce fecal contamination. Possibly treating newborn lambs with plasma, known to contain high levels of immunoglobulins, immediately following birth would deter bacterial invasion. Free-ranging bighorn ewes usually select remote areas away from the rest of the herd prior to lambing and appear with their lamb a few days to several weeks later (Geist 1971). Lamb mortality due to septicemia in free-ranging bighorns has not been reported.

A mean gestation period of captive bighorns was 174.2 ± 1.7 (SD) days (Shackleton *et al.* 1984). Geist (1971) concluded that North American mountain sheep have gestation periods of about 175 days. Based upon the data from year 2 lambing dates, the yearling ram sired five lambs born in 1987, and possibly as many as seven. This indicates that yearling rams are capable of successful breeding. Bighorn rams attain sexual maturity at about 18 months (Geist 1971, Blunt *et al.* 1977), yet normally do not successfully breed until much later (Geist 1971). In free-ranging bighorns or captive herds in which a mature ram is present, yearling rams seldom have an opportunity to breed because mature rams aggressively ward off breeding attempts of subordinate rams. In this study the yearling ram should have had ample time and opportunity to breed all 10 ewes by the removal date. It is possible that the ewes rejected the advances of this young ram, or it may be that he lacked the sexual aggressiveness that older rams demonstrate. However, transplants of yearling rams into new areas or into herds with an over-abundance of ewes can result in successful breeding. This may be important in transport situations where older rams are difficult to obtain, are considered too dangerous or physically too large to transport, or may wander far from ewes after transplantation but before breeding.

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Hydrologic Response of the Pack River, Idaho, to the Sundance Fire

Abstract

The Sundance Fire of 1967 burned 26 percent of the Pack River watershed in Idaho. Removal of the forest canopy was hypothesized to produce an increase in annual streamflow from the basin and an advance of the peak flows by virtue of decreased transpiration losses and earlier snowmelt runoff generation. Comparison of mean annual streamflow and mean monthly streamflow in the pre- and post-fire periods do not support an increase in water yield but do suggest an earlier peak flow. The assessment of annual water yield is complicated in this case by a probable decrease in post-fire precipitation amounts and a substantial increase in precipitation variability. The average half-flow date of the Pack River advanced five days following the fire. March experienced a 40 percent increase in average streamflow while June experienced a 23 percent decrease. Simulated monthly discharges, based on regression equations relating Pack River flow to that of nearby Boundary Creek, substantiate these findings. Post-fire estimates of Pack River flows, based on pre-fire regression equations, produce residuals biased in the direction indicated by the mean monthly comparisons: the March equation substantially underestimates post-fire Pack River discharge and the reverse is true for June. These results suggest that removal of canopy cover over a substantial portion of a stream basin produces earlier snowmelt and earlier peak flows in snowmelt runoff dominated watersheds. These findings have application to watershed management, prescribed burning programs, and reservoir operation in forested stream basins.

Introduction

Consideration of the storages and transfers within the basin hydrologic cycle implies that modifications of basin vegetation cover influence both the timing and amount of streamflow (More 1969). This is especially true for basins in the western United States where much of the annual streamflow is snowmelt-derived (Packer 1962). Devegetation by wildfire, logging, development and/or disease might reasonably be expected to decrease canopy storage and evapotranspiration and hasten the onset of snowmelt. Less evapotranspiration would tend to produce an increase in streamflow volume, and earlier melt to produce an advance in the annual peak flow in the affected watershed.

Numerous studies have noted increases in snow accumulation in areas cleared of canopy cover (Bates and Henry 1928, Hoover 1960, Haupt 1979a, 1979b, Gary 1979) although there is some controversy regarding the nature of this increase; whether it is real—derived from decreased sublimation—or redistributed from surrounding forest via wind (Anderson 1969, Gary 1975, Hoover and Leaf 1967). It appears likely that the increase is real in areas with warmer snowpacks where wind redistribution is less significant (Haupt 1979b, Christner and Harr 1982).

Studies have also illustrated a general increase in soil moisture after logging and/or wildfire, an effect attributed to decreased transpiration (Helvey 1980, Hart and Lomas 1983, Megahan 1983). Although there is some suggestion of proportionality, the effects of marginal disturbances (10-20%) to the vegetation cover are difficult to document (McMinn and Hewlett 1975, Bosch and Hewlett 1982).

The effects of reduced canopy cover on the snowpack energy balance equation suggest a probable change in the timing of snowpack ripening and melt. Increased shortwave flux should hasten the onset of snowmelt-derived runoff. Removal of canopy cover may also increase both Hortonian overland flow and return flow; the former due to a reduction in surface infiltration and increased water repellency of soils (Debano and Rice 1975, Morris and Moses 1987) and the latter as a consequence of a higher piezometric surface (Dunne 1978, Megahan 1983).

The Sundance Fire of northern Idaho provided an opportunity to evaluate potential changes in water yield and snowmelt timing in the Pack River watershed.

The Sundance Fire, Pack River Basin, Idaho

The Pack River drainage is located on the eastern flank of the Selkirk Crest in the Panhandle region of northern Idaho (Figure 1). Mixed coniferous forest covers approximately 95 percent of the basin, which drains 326 km² of the Kiniksu Batholith. Elevations range from 650 m to 2300 m. Slopes in the basin range from 20-35 percent, approaching 80 percent near the drainage divide, and floodplain area accounts for less than 6 percent of the basin.

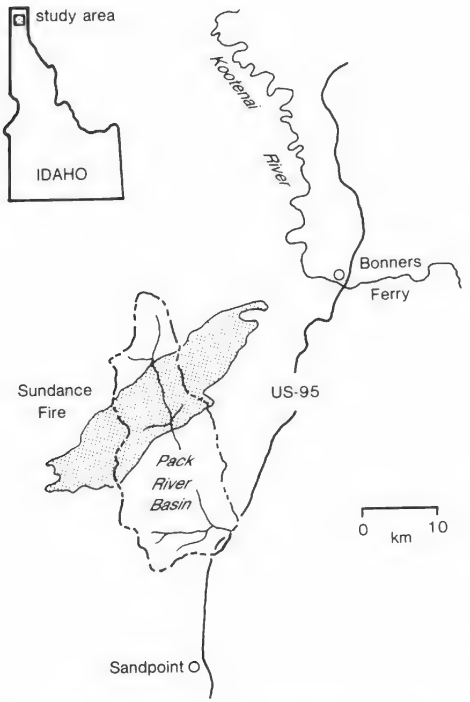

Figure 1. Location of Pack River drainage basin. Shaded portion shows extent of Sundance Fire.

The Sundance Fire was one of several large fires that occurred in the Inland Northwest during the summer of 1967 and was the subject of an extensive USDA-Forest Service report (Anderson 1968). Between 11 August and 2 September over 20,000 ha burned, including 26 percent of the Pack River watershed. Revegetation in the Pack River watershed has been studied extensively by Stickney (1984). During the first decade of regrowth, ground cover species dominated, and trees did not exceed 10 percent of the total vegetation cover within the burned area. Stickney further estimated that only two of 18 study sites would establish a tree stage in the second decade of regrowth.

Methods

Changes in the post-fire hydrology of the Pack River were assessed using both single- and paired-basin methodologies. Daily discharge data for the Pack River came from a USGS gaging station (#12-392300) near Colburn, Idaho, 15 km upstream from the inlet into Lake Pend Oreille. Precipitation data are limited to a single station at the Priest River Experiment Station (elevation 725 m) and Benton Spring snowcourse (elevation 1500 m). Both are located within the Priest River Experimental Forest, 20 km southwest of the Pack River gaging station. The total length of record was analyzed, and includes nine pre-fire years (WY 1959-1967) and 15 post-fire years (WY 1968-1982). The gaging station was discontinued in 1982. These basic data provide for comparison of average streamflow conditions during the two periods. Corroborative analyses were done using a paired-basin approach; pre-fire discharge of the Pack River was correlated with that of Boundary Creek near Porthill, Idaho (International gaging station #12-321500). This stream drains 250 km² of similar terrain approximately 40 km north of the Pack River basin. Both annual and monthly regression equations were calibrated. Similar equations were estimated using the post-fire discharge record. Differences in the pre- and post-fire regression equations were assessed in light of the residuals from pre-fire based predictions and observed Pack River discharges.

Results

Prior to the Sundance Fire, a nine-year record of streamflow suggests an average annual runoff of 899 mm. This pre-fire distribution of annual runoff has a standard deviation (s) of 113 mm. Individual years ranged from 743 mm (WY 1965) to 1063 mm (WY 1961). The mean half-flow date, the day representing the passage of 50 percent of the annual runoff, was 14 May. The shortest one-half flow interval, the shortest time within

which 50 percent of the annual runoff was measured, averaged 51.1 days.

Mean annual runoff of the 15 post-fire years was 877 mm ($s = 289$ mm). A simple comparison of means test reveals the difference to be statistically non-significant ($t = 0.22$, $\alpha = 0.41$). Mean precipitation amount and maximum snow water equivalent of the Benton Spring snowcourse likewise reveal no significant differences between the two time periods (Table 1), although these are both single point measurements, and not especially representative of the Pack River watershed. Post-fire runoff, precipitation and snow water content were 98 percent, 97 percent, and 98 percent of their respective pre-fire values. The dramatic increase in post-fire precipitation and runoff variance make it difficult to demonstrate statistically significant differences between the mean values.

TABLE 1. Statistical comparisons of annual runoff and precipitation during pre-fire versus post-fire periods.[a]

Population Means	Pre-fire	Post-fire	t-value	alpha
Runoff	899	878	0.22	0.41
Precipitation	839	812	0.41	0.34
Maximum Snowpack Water Equivalent	505	496	0.14	0.44
Population Variances	Pre-fire	Post-fire	F-value	alpha
Runoff	12,746	83,289	6.52	0.01
Precipitation	5,574	34,948	6.27	0.01
Maximum Snowpack Water Equivalent	12,890	29,741	2.31	0.11

[a]Runoff, precipitation, and maximum snow water content are given in mm.

Maximum (instantaneous) flows increased an average of 25 percent following the fire and the five highest flows on record all occurred in the post-fire period. Four of these, however, corresponded to above-average precipitation and snow water equivalent conditions, and the statistical significance of this increase is marginal ($\alpha = 0.11$). Although minimum flows increased an average of 11 percent following the fire, this difference was statistically non-significant ($\alpha 0.21$).

The average shortest one-half flow interval remained essentially unchanged (51.0 days), although the average half-flow date advanced from 14 May (pre-fire) to 9 May (post-fire). This advance is reflected in the monthly streamflow comparisons. Three months appear to have experienced post-fire changes: March (40% increase), June (23% decrease) and August (24% increase). Significance levels associated with these comparisons are 0.12, 0.09, and 0.13 respectively.

These results were the focus of paired-basin analyses utilizing discharge data from nearby Boundary Creek. The nine years of Pack River daily discharge data from the pre-fire period show close correlation with data from Boundary Creek ($R^2 = 0.89$). This correlation is statistically significant although the root mean square error is 43 percent of the mean Pack River flow. Furthermore, an examination of the average residuals from this regression strongly suggests a difference in the timing of streamflow between the two watersheds (Figure 2). The average half flow date of Boundary Creek is 25 May, 11 days later than that for the (pre-fire) Pack River.

Month interbasin correlations between the Pack River and Boundary Creek provide additional support for the post-fire increase in March streamflow and decrease in June streamflow in

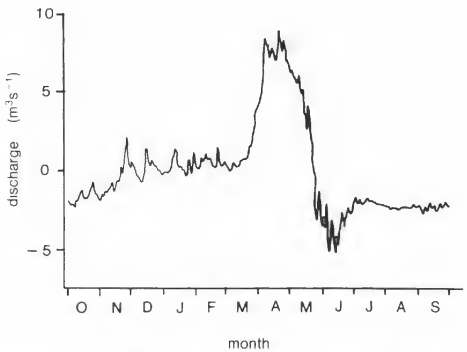

Figure 2. Average residuals from regression equation predicting daily Pack River discharge from Boundary Creek discharge for pre-fire period (1959-1967).

the Pack River basin. These regressions reveal statistically significant changes in slope coefficients between pre- and post-fire discharge estimates in the direction suggested by the comparison of mean monthly flows (Table 2). Changes in the regression parameters for August flows were not statistically significant.

TABLE 2. Comparison of pre- versus post-fire calibrated regression equations for daily flows in the months of March, June, and August. Pack River versus Boundary Creek.

	Intercept	Slope	Prob > F	R^2
Pre-fire				
March*	26.80	2.82	0.0001	0.86
June*	64.60	1.11	0.0001	0.91
August	7.81	1.07	0.0001	0.77
Post-fire				
March*	12.67	3.28	0.0001	0.75
June*	19.58	0.06	0.0001	0.91
August	5.47	0.96	0.0001	0.81

*differences in regression slope (pre- vs. post-fire) significant at $\alpha = 0.10$

Pre-fire regression equations were also used to predict pre- and post-fire streamflow for the Pack River. These predicted values were compared to observed discharges. Pre-fire residuals for March and June are generally small, although the phase differential is still apparent (Figure 3). In contrast, residuals from the post-fire period are much larger and exhibit a much more prominent bias; the pre-fire regression equations substantially underestimate post-fire streamflow for March and overestimate post-fire streamflow for June (Figure 4). Although this procedure also resulted in overestimation of August streamflow, the non-significant pre- versus post-fire regression parameter differences, and the very small residuals involved ($\cong 0.2$ m^3 s^{-1}) precludes unequivocal assessment.

Conclusions

This study is significant in that the Pack River Basin is an order of magnitude larger than basins where the effects of vegetation cover removal on streamflow have been extensively studied (Bosch and Hewlett 1982), and the disturbed area (26%)

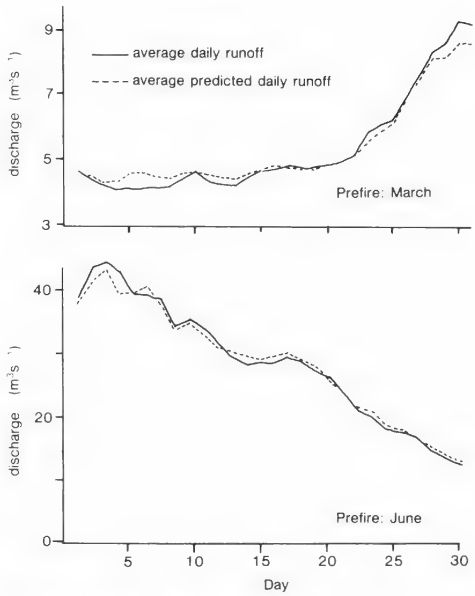

Figure 3. Average residuals for March and June from pre-fire monthly regression equations (Table 2) predicting Pack River discharge from Boundary Creek discharge.

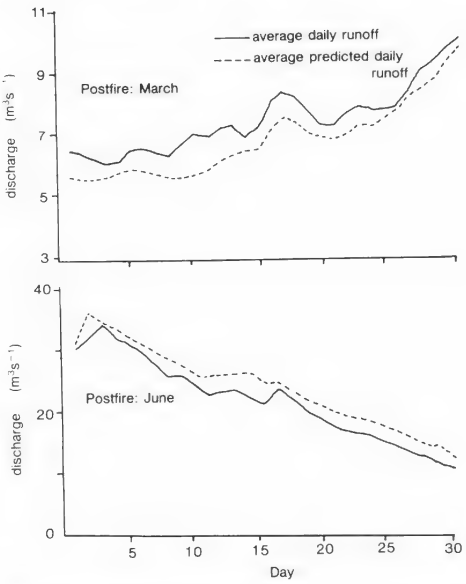

Figure 4. Average residuals for March and June from post-fire period using pre-fire predictive equations (Table 2) and post-fire observations of Pack River streamflow.

was near the lower limit of measurable hydrologic response owing to removal of canopy.

The hypothesized changes following the Sundance Fire, an increase in water yield and an earlier peak flow, are partially supported by analysis of mean Pack River streamflow and estimates of streamflow based on correlations with Boundary Creek. Although no statistically significant change in annual streamflow was discerned, this assessment is complicated by an increase in post-fire precipitation variance. Post-fire streamflow decreased 2.4 percent while post-fire precipitation declined 3.2 percent. These figures do not provide much confirmation, however, due to the probable errors in the measurement of both elements. In addition, the precipitation data (precipitation and maximum snow water equivalent) were limited to a single station whereas the watershed spans 1500 m of elevation.

Analysis of monthly streamflow and comparison of Pack River and Boundary Creek discharge do support statistically significant ($\alpha = 0.1$) increases in post-fire March streamflow and decreases in June. Comparison of the average pre- and post-fire hydrographs clearly illustrates the change in the timing of streamflow suggested by these analyses (Figure 5). Post-fire streamflow appeared to peak earlier. Although maximum instantaneous flow also increased in the post-fire period, mean monthly peaks decreased slightly. We interpret this apparent contradiction to result from short-lived peaks produced by rain on snow events in a basin with much diminished canopy cover over one-quarter of its area. Lower average peaks may reflect lower precipitation inputs of the post-fire period.

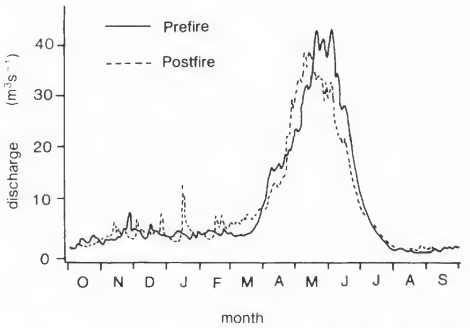

Figure 5. Average pre-fire (1959-1967) and post-fire (1968-1982) hydrographs for the Pack River, Idaho.

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Vegetation Gradient Analysis of Two Sites in Southeast Alaska

Abstract

Two study sites in Southeast Alaska, one on the mainland and one on Etolin Island, were compared for tree, shrub, and herb vegetation cover in summer, 1983. For the tree stratum, detrended correspondence analysis (DCA) indicated that soil moisture drainage and study site were the first two factors related to composition differences among samples. DCA indicated that, for the shrub stratum, study site and soil moisture drainage were the first two factors. For the herb layer, the first three factors from DCA were interpreted as soil moisture drainage, elevation, and study site respectively. Direct gradient analysis of species distributions revealed clear patterns for many species with respect to soil drainage and elevation gradients. Even though DCA did not identify elevation as a factor for the tree and shrub strata, individual species within these strata did show responses to elevation. Many species abundances were also clearly differentiated between study sites.

Introduction

The coastal forests that extend from southeastern Alaska to northern California are part of the coniferous forests of Pacific Northwest North America (Waring and Franklin 1979). Cool, maritime climates with winter rains predominate in the region. The climate, topography, and vegetation of Southeast Alaska limit the frequency and extent of natural fires, and extensive areas have been free from large-scale disturbances for great periods of time (Harris and Farr 1974). The most common natural disturbances, windfall (Ruth and Harris 1979) and slope failure (Swanston 1969), occur on a local scale.

Vegetation studies in Southeast Alaska and the nearby coastal conifer forests of British Columbia, Canada, have consisted of broad classifications and descriptions of major environmental gradients. Heusser (1960) and Neiland (1971) reviewed earlier literature. Alaback (1980), Godman (1952), Palmer (1942), Viereck and Dyrness (1980), and Worley (1974, 1975, 1977) provided various classification schemes for Southeast Alaska vegetation. Forest understory associations were described by Neiland (1971), Schoen *et al.* (1981), Rose (1982) and Ver Hoef (1985) for Southeast Alaska, and Eck (1983) for Prince William Sound.

Topography, which has a strong influence on drainage, has been identified as a major factor correlated with vegetation variation in Southeast Alaska (Lawrence 1958, Neiland 1971, Zach 1950). Orloci (1964), in British Columbia, identified moisture, elevation, and humus quality as the main environmental correlates with vegetation variation.

Although the geographic patterns of forest types are now well understood, their quantitative variation is not. One approach to this is to compare intensively studied sites. This paper reports the quantitative differences in the vegetation of two contrasting environments in Southeast Alaska. The objectives of this study were to: 1) compare quantitatively the forest vegetation on an island, which has a more maritime climate, with that of a nearby site on the mainland, which has a more continental climate, 2) identify environmental gradients underlying vegetation variation within tree, shrub, and herb strata among all stands, and 3) summarize distribution patterns of selected herb, shrub, and tree species along these major environmental gradients.

Study Area

Two study sites were sampled in summer 1983. The Quiet Harbor site is located on the western side of Etolin Island, Southeast Alaska (56°10'N, 132°40'W), approximately 40km southwest of the town of Wrangell (Figure 1). The Aaron Creek study site is located on the mainland of Southeast

Alaska (56°25'N, 131°80'W), approximately 27 km east of the town of Wrangell (Figure 1).

Southeast Alaska has a cool maritime climate (Table 1) with high rainfall. The town of Wrangell

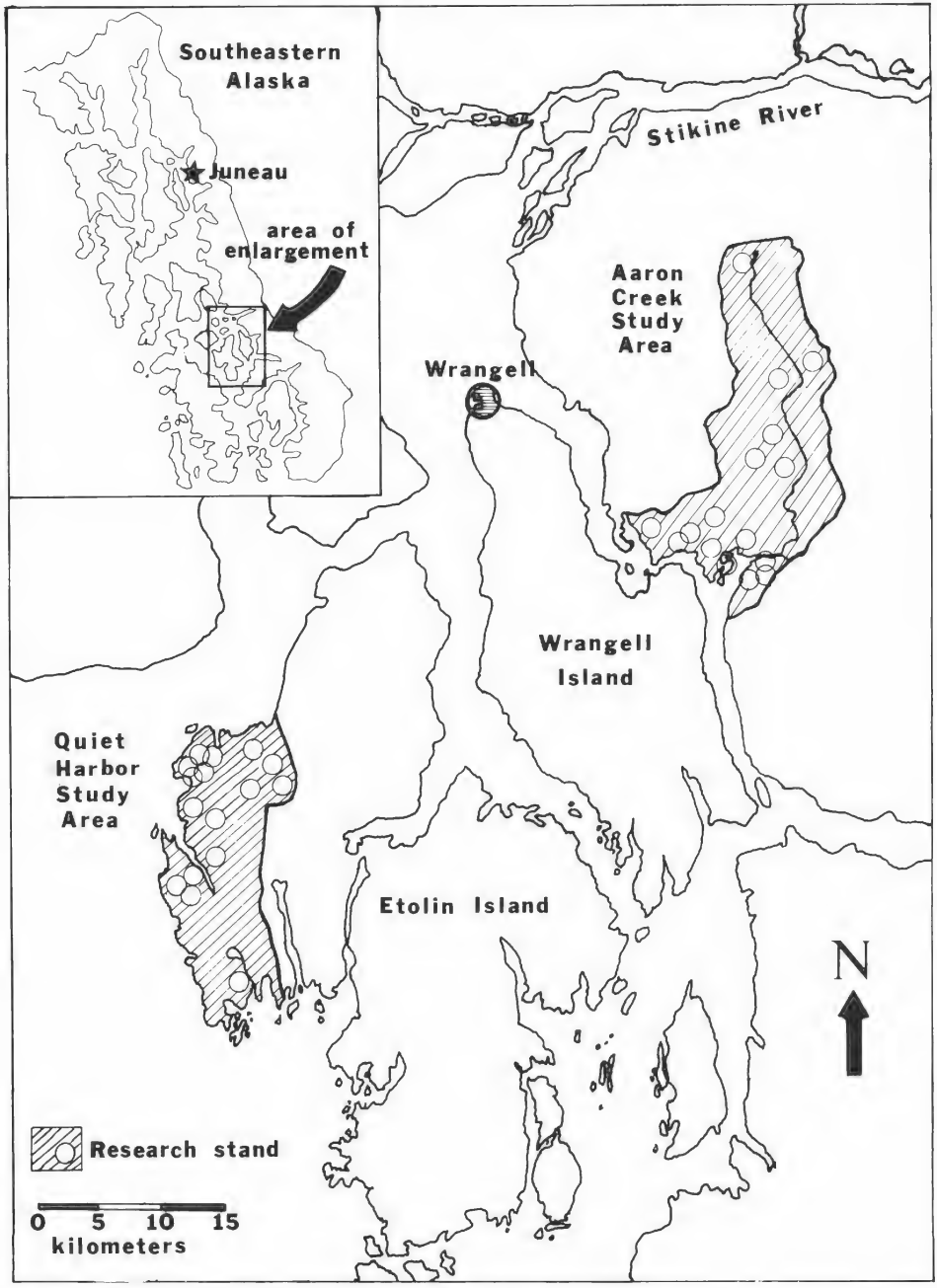

Figure 1. Map of study sites and stand locations near Wrangell, Alaska.

TABLE 1. Temperature (°C) characteristics for the Wrangell (mainland) group and Lincoln Rock group from multivariate analysis of weather stations of coastal Alaska. (source: Farr and Hard 1984). Summer: June, July, August. Winter: Dec., Jan., Feb.

	Wrangell group	Lincoln Rock Group
Daily means		
Maximum Summer Temp.	16.9	15.2
Minimum Summer Temp.	8.3	9.8
Mean Summer Daily Fluctuation	8.6	5.4
Maximum Winter Temp.	−0.1	3.9
Minimum Winter Temp.	−5.8	−0.3
Mean Winter Daily Fluctuation	5.7	4.2
Seasonal means		
Summer	12.7	12.6
Winter	−2.9	1.8
Mean Yearly Fluctuation	15.6	10.8

had the nearest weather station to the Aaron Creek study site. From 1953 to 1967, climatic data were collected at Lincoln Rock, approximately 3 km offshore from the Quiet Harbor study site. Both daily and seasonal temperature fluctuations were greater at the Wrangell station, nearest the mainland site of Aaron Creek, than at the Lincoln Rock station, nearest the island site of Quiet Harbor. Daily and seasonal highs are higher, and lows are lower, on the mainland (Table 1). Both sites had almost identical precipitation patterns, averaging approximately 200 cm per year (Farr and Hard 1984).

The Aaron Creek site soil parent material is composed primarily of crystalline metamorphic rocks, whereas the Etolin Island site is primarily underlain by Mesozoic sediments and volcanic rocks (Buddington and Chapin 1929). However, most mineral soils were formed from deep ablation till deposited by receding glaciers. Because of this overburden, bedrock has had little to do with soil development (Harris *et al.* 1974).

Soils in Southeast Alaska are predominantly spodosols, being relatively young, shallow, and poorly developed (Heilman and Gass 1974). Topography, slope angle and elevation combine to alter water drainage, temperature, and erosion, and have had a significant effect on the development of the soils (USDA Forest Service 1982). Moisture saturation and cool temperatures result in low rates of organic decomposition and slow soil development. This in turn allows significant accumulations of organic matter in the soil and on the surface. Water drainage is often impeded by the organic matter, and the most productive soils in the study areas were those that were well-drained. Both study sites contained the same soil types and were mapped under the same classification system by the USDA Forest Service, although the relative amounts of soil types probably varied between sites.

Vegetation within the two study sites included old-growth forests in a mosaic with bogs, and less extensive alpine, beach and meadow communities. Old-growth forests are defined as those greater than 300 years of age and with uneven canopy coverage due to old tree mortality. Old-growth forests within the study area ranged from open stands with approximately 35 percent cover of predominantly Alaska cedar, *Chamaecyparis nootkatensis* and western hemlock, *Tsuga heterophylla,* on poor sites, to stands with about 80 percent cover of primarily western hemlock and Sitka spruce, *Picea sitchensis,* on more productive sites. (Nomenclature follows Viereck and Little 1972, for trees and shrubs, and Hultén 1968, for herbaceous species. Voucher specimens are filed at the Wrangell Ranger District of the USDA Tongass National Forest, and at the herbarium of the University of Alaska, Fairbanks.) The study sites extended from 0 to 600 m in elevation, slopes faced in all directions, and ranged from flat to extremely steep.

Methods

Aaron Creek and Quiet Harbor were sampled from the middle of June until the middle of August, 1983. Most plants were near or had reached full size. A stand is defined as an area of relatively homogeneous coverage by the dominant tree species.

Stands were selected for sampling using a combination of topographic maps and aerial photos prepared by USDA Forest Service personnel according to soil drainage types. Only forest stands below subalpine soils were included. From these maps, three environmental gradients were recognized prior to fieldwork: 1) soil drainage, 2) elevation, and 3) aspect. Each environmental gradient was stratified into four classes in order to get even sampling among these gradients. The soil classes were based on USDA Forest Service (1982) mapping units: F1 were deep (>50 cm), well-drained soils; F2 were shallow (<50 cm),

well-drained soils; F4 were deep, poorly-drained soils; F5 were deep, very poorly-drained soils. Elevation classes were 0-60 m; 61-150 m; 151-300 m; and 300+ m above sea level. Aspect classes were: 1-90 compass degrees; 91-180 degrees; 181-270 degrees; and 271-360 degrees.

A 4 X 4 Latin square experimental design was used as a sampling scheme at each site. This allowed four stands to be sampled from each class of each gradient. A 4 X 4 Latin square was chosen randomly, and the four soil classes were given row cells and the four elevation classes were given column cells. Aspect varied within each Latin square. All stands within each study site that fit into a Latin square cell were identified from aerial photos and topographic maps. From those stands, one stand was chosen at random for each cell in the Latin square, resulting in 32 stands, 16 from each study site. All stands were "old-growth" and, following Neiland (1971), had no disturbance larger than that of a single, large, fallen tree. Stands ranged in size from approximately 1 to 3 hectares.

Data were collected from three vegetation layers. Trees were defined as woody stems greater than 5 cm diameter at breast height (dbh). Shrub layer species, including juvenile trees, were defined as woody stems less than 5 cm dbh, but greater than 40 cm tall. Herbaceous layer species included woody stems less than 40 cm tall and all herbaceous stems.

Three 20 m long, replicate random transects were run across the slope (i.e. parallel to the contour) in each stand. Absolute tree and shrub canopy cover was measured by line intercept (Canfield 1941). Ten 20 X 50 cm quadrats per transect were placed every 2 m and herbaceous cover was estimated using the following cover classes: 0-1%, 2-5%, 6-20%, 21-40%, 41-60%, 81-100%. The adequacy of 30 herb plots per stand was determined by running mean (Kershaw and Looney 1985), and was subjectively assessed as being adequate for the more abundant species but inadequate for the less abundant ones. This was accepted as a compromise that would still allow sufficient numbers of stands to be sampled over the course of the summer.

The midpoints of the cover classes for herbs, and species totals of line intercepts were used to determine mean cover values of all species per stand. Mean species cover values for all vegetation strata were subjected to detrended correspondence analysis (DCA) using the DECORANA program (Hill 1979). DCA was used because it has been judged to have superior ordination performance (Hill and Gauch 1980, Gauch 1982, Pielou 1984, Kershaw and Looney 1985).

For direct gradient analysis, average cover values for the most common species from each vegetation layer are presented in discrete classes along the soil and elevation gradients as well as by study site. Since ecological data are often statistically "noisy" (Gauch 1982), the array of means of discrete classes along gradients is a convenient way to summarize species distributions (Curtis and McIntosh 1951, Gauch 1982). No confidence intervals are presented. Stands were weighted equally for calculating mean values even though stand size may have varied. Also, sampling was uniform for the gradient classes in order to get enough stands from each class for DCA correlations, even though there may have been proportionally more stands in one class than another. In other words, the mean abundances are relative values for a particular combination of environmental factors. A correlation factor would require a weighting of the mean in the proportion to the total aerial extent of all stands within the gradient classes and such data are unavailable. In addition, the stand values themselves are estimates and subject to sampling error. The values displayed, then, are not true means for the categories. However, the values presented should reasonably reflect trends along the major gradients.

Results and Discussion

Ordination of Vegetation Samples

DCA stand scores for combinations of axes for each vegetation layer are plotted in Figure 2. Each stand is represented by a combination of letters for study site or elevation and/or a numeral for soil class. (Since DCA stand scores are weighted averages of species scores, it is possible for stand scores for axis one to cover a smaller range than axis two, even though DCA species scores had a wider range for axis one than axis two. This is the case in Figures 2a and 2b.)

The first DCA axis for trees (Figure 2a) represents a soil drainage gradient, with the well-drained stands loading in the left portion and the

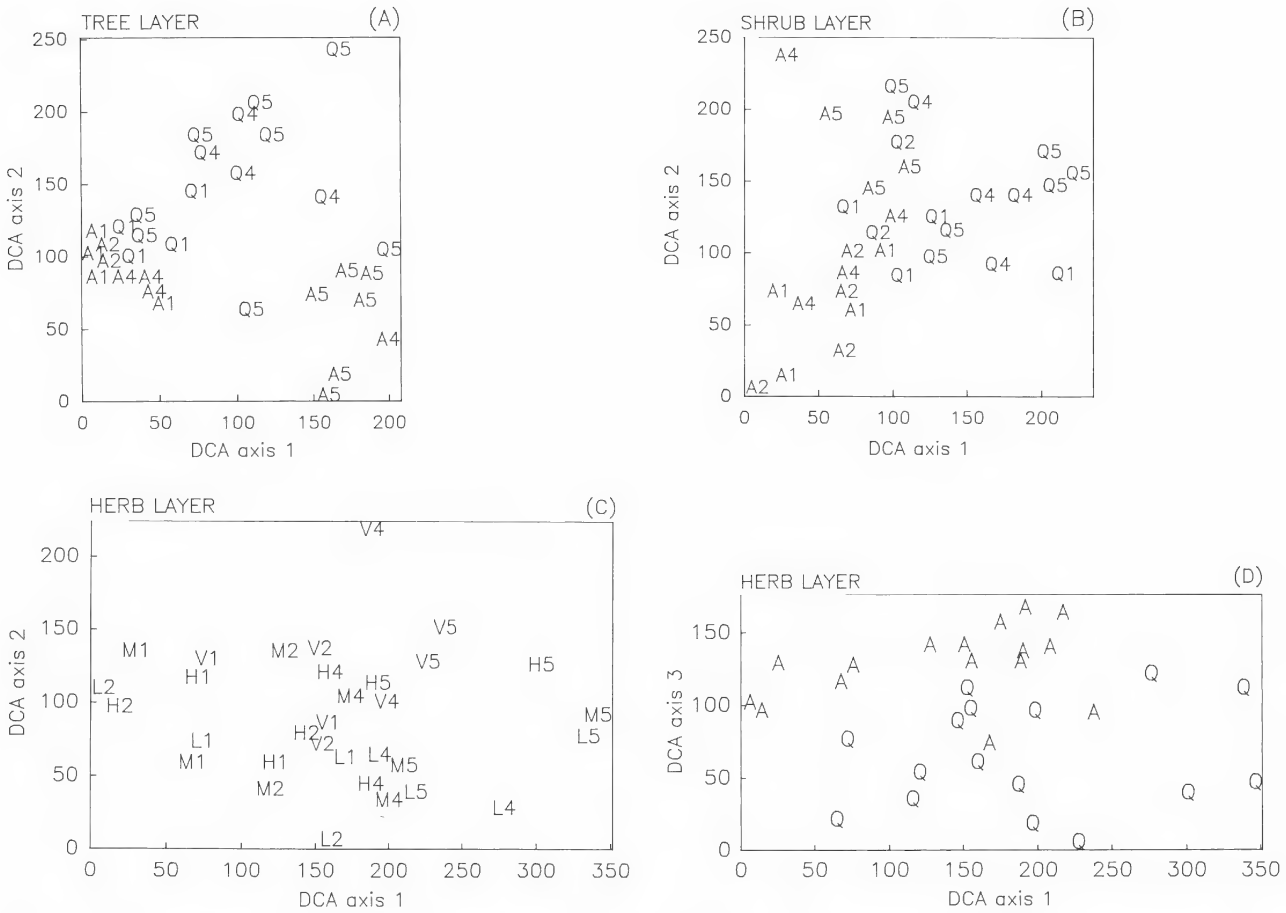

Figure 2. Detrended Correspondence Analysis (DCA) for tree, shrub, and herb layers. Symbols are at intersection of stand loadings for each DCA axis. Symbol codes for study site are: A = Aaron Creek, Q = Quiet Harbor; for soil types: 1 = F1 (deep, well-drained) soils, 2 = F2 (shallow, well-drained) soils, 4 = F4 (deep, poorly-drained) soils, 5 = F5 (deep, very poorly-drained) soils; and for elevation: L = 0-60 m, M = 61-150 m, H = 151-300 m, V = 300+ m.

poorly-drained stands loading in the right portion of the figure, with only a few exceptions. The mean DCA score on axis one is 28 for F1 stands, 72 for F2 stands, 93 for F4 stands, and 160 for F5 stands. The eigenvalue for the first axis is 0.455. The second DCA axis places the Aaron Creek stands toward the bottom of the figure and the Quiet Harbor stands toward the top (Figure 2a). The mean DCA score on axis two for Aaron Creek stands is 78 and for Quiet Harbor stands is 150. The eigenvalue for the second axis is 0.248, summarizing considerably less variation than the first axis. Thus, differences between the two study sites appear to affect tree species composition less than differences between soil drainage classes. Eigenvalues for the third and subsequent axes drop to 0.062 and lower.

For the shrub layer (Figure 2b), the first DCA axis separates Quiet Harbor stands on the right from Aaron Creek stands on the left. On axis one, the average DCA score is 57 for Aaron Creek stands and 140 for Quiet Harbor stands. The eigenvalue for the first axis is 0.311. The second axis represents stand variation along the soil drainage gradient, with well-drained stands toward the bottom and poorly-drained stands toward the top. The mean DCA score on axis two is 86 for F1 stands, 88 for F2 stands, 138 for F4 stands, and 170 for F5 stands. The eigenvalue for the second axis is 0.232. In contrast to the tree species, therefore, shrub composition exhibits greater site differences than soil class differences. Again, eigenvalues for the third and subsequent axes are low.

The first DCA axis for the herb layer (Figure 2c) represents the soil drainage gradient, with well-drained stands on the left and poorly-drained stands on the right. The mean DCA score on the first axis is 93 for F1 stands, 108 for F2 stands, 196 for F4 stands and 258 for F5 stands. The eigenvalue for the first axis is 0.488. The second axis represents herb vegetation response to elevation. Low elevation stands are located in the lower portion and high elevation stands are located in the upper portion of Figure 2c. The mean second axis DCA score is 59 for low elevation stands, 86 for moderately low stands, 96 for high stands and 132 for very high stands. The eigenvalue for the second axis is 0.246. The third axis for herbs (Figure 2d) separates Quiet Harbor stands in the lower portion of the figure, with an average DCA score of 64, from Aaron Creek stands, in the upper portion, which have an average score of 128. The eigenvalue for the third axis is 0.143. For herbs, site differences do not appear until local environmental factors of soil drainage and elevation differences are accounted for. The remaining eigenvalues are 0.049 and lower.

Each vegetation layer appears to respond differently to environmental factors. Study site separation, soil drainage, and elevation correlate well with vegetation variation at these sites, but their order of importance varies among strata. Within the geographic limits of the analysis, aspect never appeared to be important in stand ordinations.

Study site differences occur over a relatively short geographical range. The sites contain essentially the same species, and the species with the greatest cover were common to both areas. Nevertheless, the quantitative abundances of species will structure communities differently enough to allow separate recognizable patterns for the study sites. This result is most likely due to Etolin's more constant, maritime environment and Aaron Creek's more variable, continental climate (Table 1).

The vegetation responses to soil drainage compare well with findings in nearby areas. Zach (1950), Lawrence (1958), and Neiland (1971) identified drainage patterns as a major gradient in explaining vegetation variation from forest to bog communities in Southeast Alaska. They argued that slope angle (i.e. topography) and proximity to rivers or oceans are the primary influences on drainage patterns. Orloci (1964) identified soil moisture, elevation, and humus quality as the first three ordination axes for the wet hemlock subzone in southern British Columbia. However, his moisture gradient ran from ample moisture to moisture-stressed, with the highest productivity on the ample moisture end of the gradient. There were several species that were common to both this our study and to Orloci's (1964) study; they were found at the well-drained end of our gradient but at the ample moisture end of his gradient. Combined, our results and those of Orloci (1964) can be viewed as a very long moisture gradient of geographic extent, with stands ranging from moisture stressed in British Columbia to excessive moisture in Southeast Alaska.

Tree productivity is directly related to the soil drainage gradient in this study. The highest tree productivity is on F1 soils and the lowest

productivity is on F5 soils (USDA Forest Service 1982). This relationship resembles that noted by Neiland (1970), who performed polar ordinations (Bray and Curtis 1957) of stands throughout Southeast Alaska and found that the primary axis was correlated with minimum to maximum tree productivity, among other factors.

Prior to our results, elevation has not been identified as a factor contributing to forest vegetation variation in Southeast Alaska. This is likely due to the fact that previous investigators combined all strata for a stand, and scores would be largely dominated by tree species, which did not show elevation trends in this study either. Orloci (1964), in British Columbia, and others in mountainous terrain (e.g. Whittaker 1956, 1960; Beals 1969) have also found elevation trends.

Species Distributions on Environmental Gradients

Six tree species occurred in the two study areas. Several of these species show clear patterns along the environmental gradients (Figure 3). Western hemlock and Sitka spruce decrease toward poor soil drainage, while other species increase. Alaska cedar and mountain hemlock, *Tsuga mertensiana,* show increased abundance with elevation, western red cedar, *Thuja plicata,* and lodgepole pine, *Pinus contorta,* decrease, and the others appear independent of elevation. Western hemlock and mountain hemlock species are more abundant at Aaron Creek, western red cedar and lodgepole pine occur only at Quiet Harbor, and the others are probably independent of site.

Most species show a unique distribution when considering these three environmental factors. For instance, Alaska cedar and western red cedar separate more with respect to elevation than to soil drainage. The two hemlocks differ in response to soil drainage and probably to elevation, but they both are more abundant at Aaron Creek than Quiet Harbor. Western hemlock and Sitka spruce, however, exhibit rather similar trends. Western hemlock is very shade tolerant throughout its life, while Sitka spruce is only moderately shade tolerant (Harlow and Harrar 1969). Shading from the forest overstory often inhibits development of juvenile Sitka spruce. However, Sitka spruce grows vigorously in moderate to high light, is often the first successional tree species, and is long-lived. When a gap opens in the overstory, Sitka spruce is able to overtop its competitors (Harlow and Harrar 1969), thus maintaining its population in old-growth stands.

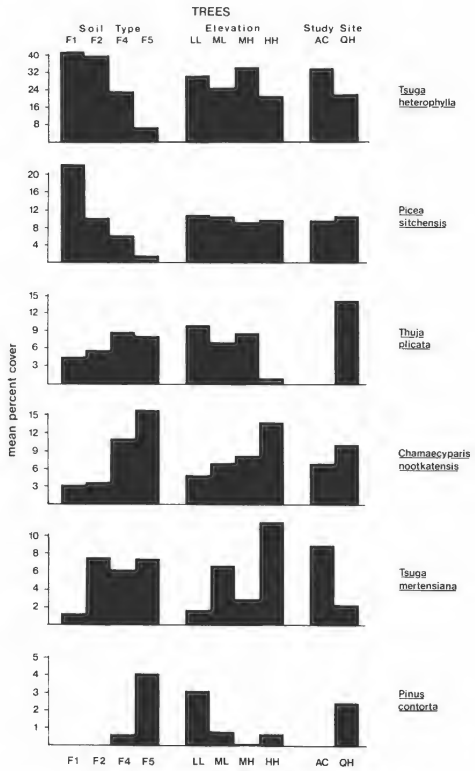

Figure 3. Direct gradient response of six tree layer species to soil type, elevation, and study site. Soils: F1 = deep, well-drained, F2 = shallow, well-drained, F4 = deep, poorly-drained, F5 = deep, very poorly-drained. Elevations: LL = 0-60 m, ML = 61-150 m, MH = 151-300 m, HH = 300+ m. Sites: AC = Aaron Creek, QH = Quiet Harbor.

Shrub species also show a response to the three environmental factors (Figure 4), the composite of which gives most of them a unique distribution. Early blueberry, *Vaccinium ovalifolium,* and Alaska blueberry, *Vaccinium alaskense,* are closely related taxa, but appear to separate based on the soil drainage gradient. As in the tree layer, many shrub species show a response to elevation, even though no elevation axis from stand ordinations was found.

Distributions of western hemlock and mountain hemlock are presented for the shrub layer

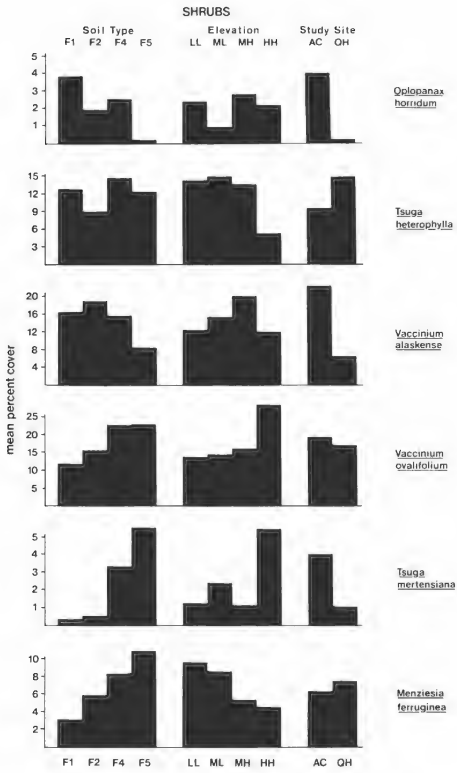

Figure 4. Direct gradient response of six shrub layer species to soil type, elevation, and study site. Symbols are the same as for Fig. 3.

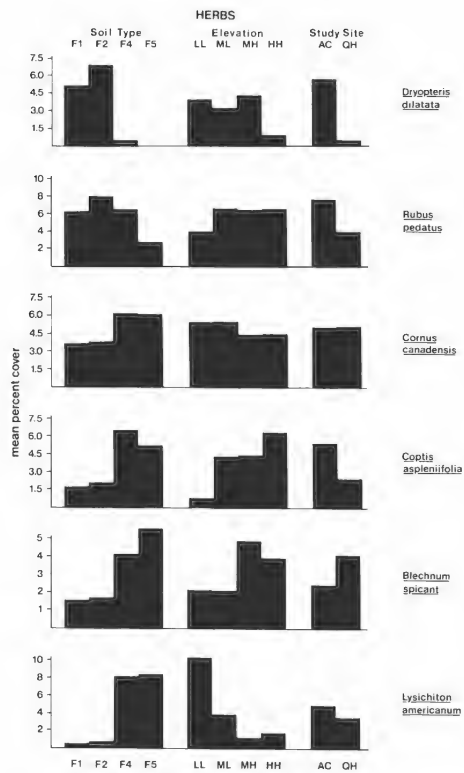

Figure 5. Direct gradient response of six herb layer species to soil type, elevation, and study site. Symbols are the same as for Fig. 3.

as well as the tree layer. The distribution of juvenile mountain hemlocks closely resembles that of mature mountain hemlocks. However, mature western hemlock and juvenile western hemlock show an inverse relationship between sites and perhaps along the soil drainage gradient. Although the exact factors controlling juvenile establishment and mature tree success are unknown, there have been similar findings in other areas (Walker *et al.* 1972).

There are clear distribution patterns for six common herbaceous species along the environmental gradients (Figure 5). Again, most show a unique distribution. Rose (1982) and Schoen *et al.* (1981) did an agglomerative clustering of understory species in Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) habitat in Southeast Alaska. Their results suggest that five-leaf bramble, *Rubus pedatus,* Canadian dogwood, *Cornus canadensis,* and fernleaf goldthread, *Coptis aspleniifolia,* are part of an association which grows on productive sites, while Devil's club, *Oplopanax horridum,* and skunk cabbage, *Lysichiton americanum,* are part of an association of poorly-drained areas and less productive sites. Our results indicate that, over the whole range of forest conditions, Canadian dogwood and fernleaf goldthread are not good indicators of well-drained sites (Figure 5), while Devil's club grows most abundantly on the well-drained soils (Figure 4). The most likely explanation for this discrepancy is that Schoen *et al.* (1981) and Rose (1982) sampled only on F1 and F2 soils, which support the only suitable forests as winter deer habitat, since forests on F4 and F5 soils do not have anough canopy coverage. Also, they clustered samples of 1.0-m² quadrats. Thus their results are more indicative of microsite factors

within well-drained stands than factors operating among stands over the range of forest conditions.

The combination of indirect and direct gradient analysis revealed that these forests vary continuously along the drainage gradient, with open stands (approximately 35% cover) of predominantly Alaska cedar, red cedar, mountain hemlock, lodgepole pine, early blueberry, rusty menziesia (*Menziesia ferruginea*), Canadian dogwood, fernleaf goldthread, deer fern and skunk cabbage on very deep, very poorly-drained soils; to closed stands (approximately 85% cover) of predominantly western hemlock, Sitka spruce, Devil's club, Alaska blueberry, wood fern (*Dryopteris dilatata*), and five-leaf bramble on deep, well-drained soils.

An important conclusion from the comparison of direct and indirect ordination methods concerns the nature of vegetation response versus species response to environmental gradients. Many species showed a response to elevation, yet, when each stratum as a whole was subjected to ordination (DCA), only the herb layer showed a response to elevation. Thus, the interaction of species was not sufficiently correlated along the elevation gradient in the tree or shrub layers to be detected by DCA. It remains to be seen how prevalent this finding is in other areas.

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Distribution of the Wolverine in Idaho as Determined by Mail Questionnaire

Abstract

The wolverine was once thought to be extinct in Idaho, but reports of its occurrence persist. In order to better determine the status and distribution of this rare species, questionnaires were sent to biologists and trappers statewide in 1985. Responses to the questionnaires resulted in 10 confirmed and 89 probable reports of wolverines in Idaho between 1960 and 1987. At least three areas in the state (Selkirk Mountains, Lochsa and Kelly Creek drainages, Sawtooth and Smoky Mountains) appear to contain wolverine populations. These areas can be characterized as remote, mountainous habitat with little human disturbance. The present-day distribution of the wolverine in Idaho is probably in the mountainous portions of the state from the South Fork of the Boise River north to the Canadian border. Although this survey has provided insights into the current distribution of the wolverine in Idaho, detailed analysis on population status and ecology are needed.

Introduction

Wolverine (*Gulo gulo*) numbers declined steadily in the contiguous United States (Wilson 1982) after the late 1800s. Today, they are uncommon in the lower 48 states and likely only occur in Oregon, Washington, California, Idaho, Montana, and Wyoming. Davis (1939) believed the wolverine to be extinct in Idaho by the 1930s. Pengelly (1951) summarized seven records of wolverine in Idaho from 1930 to 1949. These records were primarily from the northern Idaho counties of Bonner, Boundary, Kootenai, and Shoshone. The next verified records of wolverines in the state were two kills, one in northern Idaho in 1953 and one in southern Idaho in 1954.

Larrison and Johnson (1981) considered the wolverine to be rare and restricted in distribution to areas north of the Salmon River Mountains and to the mountains of southeastern Idaho. Because of its restricted distribution and apparent rarity in Idaho, the Idaho Department of Fish and Game has classified the wolverine as a protected species since 1965. In addition, Region 1 of the U.S. Forest Service, which includes northern Idaho, and the U.S. Bureau of Land Management in Idaho have designated the wolverine as a Sensitive Species. The U.S. Fish and Wildlife Service, under the authority of the Endangered Species Act, has listed the wolverine as a candidate for federal listing as a threatened or endangered species (U.S. Fish and Wildlife Service 1985). To better determine the status and distribution of the wolverine in Idaho, I mailed questionnaires to wildlife biologists and registered trappers throughout Idaho in 1985. The purpose of this paper is to report the results of the 1985 survey.

Methods

During May 1985, questionnaires on wolverine sightings were mailed to all Idaho Department of Fish and Game biologists, conservation officers, and land managers; wildlife biologists in Idaho employed by the U.S. Forest Service, U.S. Bureau of Land Management, U.S. Bureau of Reclamation, and the U.S. Fish and Wildlife Service; academicians and graduate students in biology, zoology, and wildlife departments at Idaho universities and colleges; Nongame Citizens Advisory Committees; the National Audubon Society chapters in Idaho; and state park managers. Concurrently, similar questionnaires were mailed to trappers licensed by the Idaho Department of Fish and Game.

The questionnaire sent to biologists asked respondents to provide information on the date, location (place name, county, latitude/longitude or township-range-section), habitat type, and type of observation (animal, tracks, scat) they had made, if any, during the last 25 years. Biologists were also asked to provide the name, address, and phone number of other people they knew who had information on wolverine sightings in the state.

Each licensed trapper was sent a cover letter explaining the purpose of the wolverine survey along with an addressed and postage-paid postcard for them to return with information on wolverine sightings. The postcard provided them with space to list their name, address, and telephone number; their general trapping area; a "yes" or "no" on whether they had trapped or seen wolverines or wolverine sign during the last 25 years; and the date and area where wolverines or sign had been observed.

Follow-up telephone calls were made to all individuals (biologists and trappers) that responded positively to the wolverine survey. Confirmed wolverine reports consisted of either a photograph or a carcass. For those reports that were not confirmed (i.e., sightings of wolverines or tracks), respondents were asked for a description of the animal, their level of confidence that they had seen a wolverine or tracks of a wolverine, whether they had previously seen a wolverine, the distance and amount of time of their observation, and their amount of experience as a biologist or trapper. If the observer lacked confidence in his/her observation, poorly described the animal, or saw it for a short time span and/or at a great distance, I did not include the wolverine observation in this report. Sightings of wolverines or wolverine tracks included in this paper are referred to as probable reports.

Results and Discussion

One hundred eighty-five of the 296 biologists who were mailed the questionnaire responded to the survey for a return rate of 62.5 percent (Table 1). Thirty-seven of these 185 reponses reported observations of wolverines or wolverine sign. Thirty-five of 427 responding trappers reported observations of wolverines or wolverine sign. Some positive responses from biologists and trappers included information on more than one wolverine report. Thirty-five positive reports returned by biologists or trappers were not included in this report due to insufficient information or lack of credibility in the report.

The survey resulted in only 10 confirmed reports of wolverine in Idaho between 1960 and 1986 (Table 1, Figure 1).[1] Eight of these 10 reports came from northern Idaho north of the Lochsa River, and all but two reports were from national forest lands. Five of the reports occurred between 1960 and 1975 while the other half occurred between 1976 and 1986.

I documented 89 probable reports of wolverines or wolverine tracks between 1960 and February 1987 (Table 1, Figure 1). Nine of these reports (10%) occurred from 1960-1969, 28 (32%) from 1970-1979, and 52 (58%) from 1980-1987. Twenty-one percent of the probable reports were from Bonner and Boundary counties in extreme northern Idaho. Eighteen percent of the reports occurred in the north-central counties of Clearwater and Idaho, and another 22 percent came from a cluster of south-central counties (Custer, Elmore, Blaine, Camas, and Boise).

At least three areas in Idaho, from which confirmed and probable reports were received, appear to contain wolverines. These areas are the Selkirk Mountains adjacent to and north of Priest Lake, the Lochsa and Kelly Creek drainages, and the headwaters of the South Fork and Middle Forks of the Boise River (i.e., Sawtooth-Smoky Mountains) (Figure 1). Several confirmed reports also occurred in the Purcell Mountains north of the Kootenai River, but all of these reports were prior to 1965. Because the longevity of wolverines in the wild is 8-10 years (Wilson 1982), these reports were not indicative of present-day occupancy by wolverines.

Concentrations of probable reports indicated that wolverines also likely occur in Fremont County adjacent to Yellowstone National Park and in the upper St. Joe and Coeur d'Alene River drainages. The Selway and Salmon River drainages in central Idaho were conspicuously absent of any confirmed reports and contained only a few probable reports. The lack of wolverine reports in these areas may reflect their roadless nature and low density of people, particularly biologists and trappers. If we assume that wolverines do occur in these areas, then the present-day distribution of wolverines in Idaho is in the mountainous portions of the state from the South Fork of the Boise River north to the Canadian border.

In a study of wolverines in western Montana, Hornocker and Hash (1981) concluded that wilderness or remote country where human activity was minimal appeared essential to maintaining

[1]Information on the observer's name, affiliation, date of observation, and exact location of observation for confirmed and probable reports is available from the author on request.

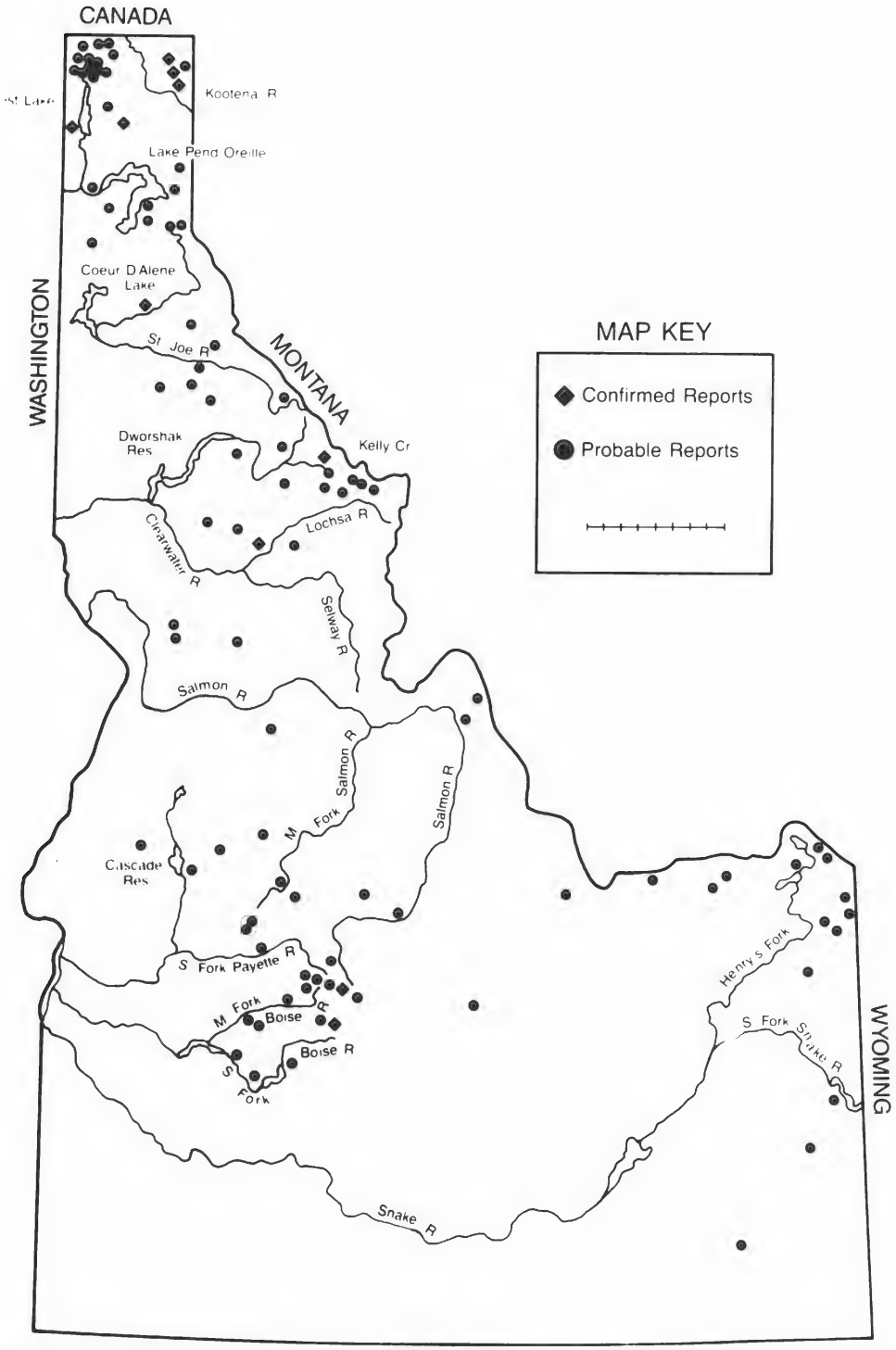

Figure 1. Distribution of wolverine reports in Idaho, 1960-1987. See text for definition of confirmed and probable reports.

TABLE 1. Summary of questionnaires mailed, response rates, and resulting numbers of confirmed and probable wolverine reports. See text for details.

Category	Number of Questionnaires Mailed	Number of Questionnaires Returned (%)	Number of Positive Responses (%)	Number of Confirmed Wolverine Reports	Number of Probable Wolverine Reports		
					Total	Tracks	Sightings
Biologists	296+	185 (62.5%)	37 (20%)	6	57++	16	41
Trappers	1,500	427 (28.5%)	35 (8.2%)	4	32	16	16
Total	1,796	612 (34.1%)	72 (11.8%)	10	89	32	57

+ Twenty-one responses were received from individuals not included in the original (n = 296) mailing. Eleven of the 21 responses were positive. Those positive responses that resulted in probable wolverine reports were included in this table (++).

a viable wolverine population. Although results of this survey can offer no insights to the viability of wolverine populations in Idaho, it does appear that wolverines are occupying large, mountainous, essentially roadless areas in Idaho. In the Montana study, wolverines used both wilderness and non-wilderness areas, although the latter areas were used primarily in winter when human activity was minimal. Such may also be the case in Idaho because many of our reports occurred during winter.

G. Koehler (pers. comm.) suggested that wolverines may be increasing in northern Idaho due to numerous reports. Hoak *et al.* (1982) made a similar conclusion for the wolverine in western Wyoming. Because more than half of the wolverine reports compiled during this survey occurred between 1980 and 1987, there is a tendency to similarly suggest that wolverines are increasing in Idaho. However, such a conclusion could be misleading. In analyzing the historical abundance of wolverines in Washington, Johnson (1977) correctly pointed out that in earlier times less access was available to remote areas and the total number of people in the field was less. In addition, no effort to assemble information on wolverine distribution, such as in the present survey, was conducted in the past. Thus, the increasing number of wolverine reports in Idaho from 1960 to 1987 could just as easily be attributed to greater access to remote areas, more people in the field, and no prior survey efforts, as to increasing numbers of wolverines in the state.

Surveys such as this one can provide insights to the distribution of a species but are of little aid in estimating population size. Hornocker's and Hash's (1981) study in western Montana showed that wolverines occupy annual home ranges of approximately 400 km^2. A recent study of wolverines in Alaska documented a long distance movement of 378 km by an adult wolverine (Gardner *et al.* 1986). In addition, longevity of wolverines in the wild is 8-10 years with a possible maximum of 18 years (Wilson 1982). Thus, over several years a small number of individuals could be responsible for a large number of sightings over widespread areas in Idaho. Results of this survey indicate where wolverines likely occur in the state. What is needed now is information on the size, status, and ecology of wolverine populations in Idaho.

Acknowledgments

K. Reese kindly assisted in the distribution of the questionnaire. Many thanks are due to G. Kaltenecker and P. Peterson for assistance in mapping and computerizing data from the survey. Thanks also to J. Beecham, B. W. O'Gara, W. Melquist, and two anonymous reviewers for helpful comments on the manuscript.

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LETTERS TO THE EDITOR

Volcanism and Extinctions

Editor,—Readers of the informative article on the possible causes of the Cretaceous-Tertiary boundary extinctions by Drake and Herman (1988) in *Northwest Science* might be interested to learn of recent research on the extraordinary eruptions which formed the Indian Deccan plateau [southern India].

A major hurdle in making a convincing association between Deccan volcanism and the extinctions has always been the uncertainty about the age and duration of these eruptions. As noted by Courtillot *et al.* (1986), published dates for these eruptions have ranged from 110 Ma to 30 Ma (the Cretaceous-Tertiary boundary is approximately 67 Ma). These dates are, however, patently unreliable as they were made on basalt samples of unknown stratigraphic position and relative age, while field evidence has reported no sign of the erosion between eruptions which would be expected over such a long eruptive period.

Using techniques developed on the Columbia Plateau, a major international research effort has been made over the last ten years to identify and map individual stratigraphic units within the Deccan volcanic pile. Teams from the U.S., India, and Britain have cooperated to show that the Deccan basalts were erupted very rapidly from a huge shield volcano in the north, over what is now Kalsubai Mountain, and that the younger basalt lavas flowed progressively off its southern flank as either the center of volcanic activity moved south or, more probably, the Indian continent drifted north across a "hotspot" anchored in the mantle below the continental crust. Fourteen basalt formations, each containing many separate lava flows, have been recognized and mapped over 50,000 km^2 of the best exposed part of the Deccan (Beane *et al.* 1986).

The entire volume of the Deccan lava was found to be made up of tholeiitic basalt and no evidence was seen of any significant time gap between eruptions throughout the whole 2000 m thick sequence. We can also confirm that the sequence includes only two paleomagnetic reversals (bottom-N-R-N-top). The complete stratigraphic pile has now been dated at Oregon State University using 39Ar/40Ar techniques (Duncan and Pyle, in press). The dating results confirm Courtillot's predictions. No significant difference could be found in the age of the flows from bottom to top of the basalt pile. In the words of Duncan and Pyle "the entire sequence was erupted rapidly, over perhaps less than one million years, at the Cretaceous-Tertiary boundary."

What has this to do with widespread extinctions? It has now been shown, beyond reasonable doubt, that the Deccan eruptions coincide very precisely with the extinctions at 67 Ma and evidence strongly suggests that the huge Deccan eruptions (which have ten times the volume of the Columbia River basalts) occurred in an extraordinarily short time. Massive eruptions certainly do affect the earth's climate (Rampino *et al.*, 1986, calculate that a single eruption of the large Rosa flow on the Columbia Plateau could have lowered the earth's average temperature by 1°C) so the huge volume and unusual rapidity of the Deccan eruptions must have produced a marked effect on the world's climate—at exactly the time of the main extinctions. Without repeating the arguments so well listed by Drake and Herman, may I just note that, if the extinctions were due to meteorite impact, then the simultaneous occurrence of perhaps the most devastating volcanic episode in the Earth's history must be counted an amazing coincidence.

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Willis B. Merriam, Adolph Hecht, and **Rufus W. Kiser**

A Brief History of the Northwest Scientific Association: 1960-1972

1960

The 1960 meeting of the Northwest Scientific Association was its thirty-fourth held jointly with the Idaho Academy of Science at the University of Idaho, Moscow, Idaho on December 28-29, 1960. The officers of the year were: John R. Roberts, Pacific University, President; Kenneth E. Hungerford, University of Idaho, Vice President; Willis B. Merriam, Washington State University, Secretary-Treasurer. The editor of *Northwest Science* was Joseph W. Mills, and associate editor, Kenneth E. Hungerford. The Trustees were: Earl F. Cook, University of Idaho; Royce G. Cox, Potlatch Forest, Inc.; Reuben A. Diettert, Montana State University; John W. Duffield, Greeley Forest Nursery; Henry P. Hansen, Oregon State College; Harry C. Harmsworth, University of Idaho; Robert E. Hosack, University of Idaho; Leo O. Hunt, Bureau of Land Management; Charles D. Leaphart, U.S. Forest Service; Robert S. MacLauchlan, Soil Conservation Service; T. J. O'Leary, S.J., Gonzaga University; W. Frank Scott, Washington State University; Richard B. Walker, University of Washington; A. E. Weissenborn, U.S. Geological Survey.

Robert W. Burns, Jr., Science Librarian at the University of Idaho gave the luncheon address entitled, "Machine Information Retrieval—A new game of button, button...." Approximately a hundred papers were scheduled for the two days including a symposium on "The Palouse" with topics ranging from its geology, history, and land use to its ecology. Section meetings and papers included botany-zoology, chaired by Lorin W. Roberts, University of Idaho; chemistry-physics, chaired by Andrewa Noble, Pacific University; engineering, chaired by Melbourne L. Jackson, University of Idaho; forestry, chaired by Richard Bingham; geology-geography, chaired by Rolland R. Reid, University of Idaho; social science, chaired by Harry Harmsworth, University of Idaho; soil and water conservation, chaired by E. W. Tisdale, University of Idaho.

1961

The thirty-fifth annual meeting of the association was held on December 27-28, 1961, at the Davenport Hotel in Spokane. Officers for that year were: Kenneth E. Hungerford, College of Forestry, University of Idaho, President; Willis B. Merriam, Dept. of Geography, Washington State University, Vice-President; and Earl J. Larrison, Dept. of Biological Sciences, University of Idaho, Secretary-Treasurer. The Trustees were: Earl F. Cook, University of Idaho; Royce G. Cox, Potlatch Forest Inc.; Reuben A. Diettert, Montana State University; Henry P. Hanson, Oregon State University; Harry C. Harmsworth, University of Idaho; Robert E. Hosack, University of Idaho; Leo O. Hunt, Bureau of Land Management; Robert S. MacLauchlan, Soil Conservation Service, W. Frank Scott, Washington State University; and Richard B. Walker, University of Washington. New members on the Board of Trustees were: George H. Barnes, Oregon State College; Richard T. Bingham, North Idaho Forest Genetics Center, Moscow, Idaho; Bruce V. Ettling, Washington State University; David G. Fellin, USFS, Missoula, Montana; J. Hoover Mackin, University of Washington. Honorary Trustees were: Edwin F. Heacox, Weyerhaeuser Timber Company, Tacoma, Washington; The Rev. Edmund Morton, Gonzaga University, Spokane; W. H. Rathert, J. Neils Lumber Company, Portland, Oregon.

General Association speakers were Dr. Winslow R. Hatch, Coordinator, Clearinghouse of Studies on Higher Education, Office of Education, Department of Health, Education and Welfare, Washington, D.C., who spoke on, "The

Quest for Quality" and Dr. Henry W. Smith, Professor of Soils, Department of Agronomy, Washington State University, who led the Symposium on "Effective Communication of Scientific Information" with a paper on "Illustrative Material for Scientific Talks."

Eight Sections had programs, and 91 papers were presented under the coordination of Dr. C. Gardner Shaw, Dept. of Plant Pathology, Washington State University.

Program contributors included Maurice T. James, Richard W. Dingle, E. F. Wicker and Willis B. Merriam, Washington State University; Charles J. Flora, William J. Dittrich, Walter J. Sanders and Arnold M. Lahti, Western Washington State College; John T. Young and Harry Cannon, University of British Columbia, Canada; R. W. Kiser, Centralia College; Robert D. Bratz, College of Idaho; Vera Louise Engstrom-Heg, Idaho State College; I. T. Myres and Randall E. Brown, General Electric Company; Vernon S. Robinson and William R. Marr, Potlatch Forests Inc., Lewiston, Idaho; James Dick, Weyerhaeuser Timber Company, Centralia, Washington; Philip C. Johnson, Intermountain Forest and Range Experiment Station; Carl G. Krueger, Coeur d'Alene National Forest; Hans Riekerk, University of Washington; Jerry F. Franklin and Denis P. Lavender, Oregon State University; Ewart M. Baldwin and Carl L. Johannessen, University of Oregon; Verle Kaiser, USDA Soil Conservation Service, W. H. Baker, W. R. Parish and R. R. Furgason, University of Idaho.

Honorary Life Members named at the annual banquet were Leona M. Sundquist, James C. Evenden and Dwight S. Jeffers. The outstanding scientists honored by the association were Homer J. Dana, C. P. Ross, and A. L. Anderson.

The number of members in the Association was 348 and the registered attendance at the annual meeting 155.

1962

The thirty-sixth meeting of the Northwest Scientific Association was held on December 27-28, 1962, at Western Washington State College, Bellingham, Washington. The officers for 1962 were: Willis B. Merriam, Washington State University, President; William H. Baker, Department of Biological Sciences, University of Idaho, Vice-President; Earl J. Larrison, Department of Biological Sciences, University of Idaho, Secretary-Treasurer. The Trustees were: George H. Barnes, Oregon State University; Richard T. Bingham, North Idaho Forest Genetics Center; Royce C. Cox, Potlatch Forests Inc.; Reuben A. Diettert, Montana State University; Bruce V. Ettling, Washington State University; David G. Fellin, Forest Insects Laboratory, USFS; Henry P. Hanson, Oregon State University; Robert E. Hosack, University of Idaho; W. Frank Scott, Washington State University; Richard B. Walker, University of Washington. New Trustees were: H. Kenneth Hossom, Eastern Washington State College, C. Gardner Shaw, Washington State University; George Neff, U.S. Bureau of Reclamation; and Paul H. Sunset, Washington State University. The Honorary Trustees were: F. A. Gilfillan, Dean Emeritus of Science, Oregon State University; James L. Jarrett, President, Western Washington State College; and J. R. Simplot, Boise, Idaho.

The General Association Speaker was James S. Bethel, Associate Dean, Graduate School, University of Washington, who spoke on, "The Role of the National Science Foundation in the Support of Science." A General Symposium on "Cycling of Mineral Nutrients in Ecological Systems," was led by Dr. Stanley P. Gessel, College of Forestry, University of Washington.

Eight Sections had meetings with a total of 107 papers presented. The program Chairman was Dr. Richard B. Walker, Botany Department, University of Washington.

Others prominent in section programs included R. B. Walker, Mark Behan, Hans Riekerk, Wayne Swank, and Julian D. Barksdale, University of Washington; Bruce V. Ettling, Roald Fryxell, Roger C. Brown, and Willis Merriam, Washington State University; John Shrader, Central Washington State College; Henry P. Hanson, W. K. Ferrell and Denis P. Lavender, Oregon State University; Richard P. Pharis, Pacific Northwest Forest and Range Experiment Station; Lee O. Hunt, Bureau of Land Management, Winston, Oregon; John W. Duffield, Industrial Forest Association; A. Kazak, Philip G. Haddock, Wilbert R. Danner and Rex Boughton, University of British Columbia; Otis W. Freeman, Eastern Washington State College; Dee Molenaar, Washington State University; E. E. Tylutki, Kenneth E. Hungerford, Craig MacPhee and Earl J. Larrison, University of Idaho; Robert K.

Campbell, Weyerhaeuser Co.; R. E. Brown, General Electric Co., Hanford; James Habeck, Montana State University; William G. Wilson, Whitworth College; William Bender, Arnold M. Lahti, Western Washington State College; Rufus W. Kiser, William A. Batie, Centralia Community College.

Honorary Life Members named at the annual banquet were Dr. Ethel P. Westwood, J. H. Christ, and Homer J. Dana. No outstanding scientist was named.

The Secretary reported a membership of 325. Number of papers presented at the meeting was 109.

1963

The thirty-seventh annual meeting of the Northwest Scientific Association was held on December 27-28, 1963, at the Davenport Hotel in Spokane, Washington. The officers of the Association were William H. Baker, Department of Biological Sciences, University of Idaho, President; Richard B. Walker, Botany Department, University of Washington, Vice President; Bruce V. Ettling, Washington State University, Secretary-Treasurer.

The Trustees were: George H. Barnes, School of Forestry, Oregon State University; Richard T. Bingham, North Idaho Forest Genetics Center; Royce C. Cox, Potlatch Forests Inc., Lewiston, Idaho; Reuben A. Diettert, Botany Department, Montana State University; David G. Fellin, Forest Insect Laboratory, USFS; H. Kenneth Hossom, Social Sciences Department, Eastern Washington State College; Earl J. Larrison, Department of Biological Sciences, University of Idaho; George Neff, U.S. Bureau of Reclamation; W. Frank Scott, Geology Department, Washington State University; C. Gardner Shaw, Plant Pathology Department, Washington State University; Paul H. Sunset, Chemistry Department, Oregon State University. New Trustees were: William K. Ferrell, School of Forestry, Oregon State University; Phillip G. Haddock, Faculty of Forestry, University of British Columbia; Frank Nicol, Eastern Washington State College. Honorary Trustees were James H. Jensen, President, Oregon State University; Boyd Rasmussen, Missoula, Montana and George Allen, Weyerhaeuser Company.

The General Association speaker was Dr. Helmut K. Buechner, Professor of Zoology, Washington State University on, "The Significance of Territorial Behavior in an African Antelope." Dr. Adolph Hecht was the Program Chairman. Ninety papers were presented at the eight section meetings. The following sections were represented: Botany-Zoology, Chemistry-Physics-Mathematics, Engineering, Forestry, Geology-Geography, Science Education, Social Sciences and Soil and Water Conservation. The Association membership was 326 and the registered attendance at the annual meeting, 180.

Prominent speakers taking part in the Section meetings were: Bruce V. Ettling, Mark F. Adams, Richard W. Dingle, Willis B. Merriam, Roald Fryxell, and Ben Roche, Washington State University; Richard B. Walker, Ronald E. Brown, V. Standish Mallory and Julian D. Barksdale, University of Washington; Ernest H. Lund, and Ewart M. Baldwin, University of Oregon; Martin R. Kaatz, Central Washington State College; Walter Highberg, U.S. Weather Bureau; Bob Hemstreet, Washington State Department of Game; K. L. Walters, U.S. Geological Survey; Orlo Krauter, Soil Conservation Service; William P. Barnes, University of Idaho; E. J. Davis, Gonzaga University; C. J. Diers, Weyerhaeuser Company Research Center; Raymond J. Boyd Jr., William Beaufait, Intermountain Forest and Range Experiment Station; Louis L. Walters, University of British Columbia; David A. Stephenson, University of Nevada; James M. Ford, Skagit Valley Community College; William A. Long, Washington State Department of Natural Resources; Sister Marian Catherine, Holy Names Academy; Rufus W. Kiser; Centralia Community College; Richard J. Rector, Northern Pacific Railway; Jerry F. Franklin, James M. Trappe, Robert F. Tarrant, Kenneth W. Kruger, Pacific Northwest Forest Range Experiment Station; James R. Habeck, L. C. Merriam Jr., Montana State University; William G. Wilson, Whitworth College; Randall E. Brown, General Electric Co.; Stanley N. Hersch, Robert Pfister, Northern Forest Experimental Station; J. Stewart Lowther, University of Puget Sound.

Honorary Life Membership was granted to Henry P. Hansen, Dean of the Graduate School, Oregon State University and to Willis B. Merriam, Department of Geography, Washington State University.

There was no outstanding scientist named for the year 1963. It was with great regret the passing of Professor Edwin H. Steffen, long associated with Forestry at Washington State University, was noted.

1964

There was no regular meeting in 1964. By action of the Trustees and the Executive committee the meetings were changed from the Christmas vacation in December to an early spring meeting to be held in March or April. The elected officers for 1964 carried over until the spring meeting in 1965. The officers of the Association for 1964 were: Francis J. Schadegg, Eastern Washington State College, President; Adolph Hecht, Washington State University, Vice President; Bruce V. Ettling, Washington State University, Secretary-Treasurer. The Trustees were: Royce C. Cox, Potlatch Forest Inc.; Reuben A. Diettert, Department of Botany, Montana State University; William J. Dittrich, Department of Physics, Western Washington State College; William K. Ferrell, School of Forestry, Oregon State University; Philip G. Haddock, Faculty of Forestry, University of British Columbia; H. Kenneth Hossom, Department of Social Sciences, Eastern Washington State College; George Neff, U.S. Bureau of Reclamation, Ephrata, Washington; Frank Nicol, Department of Biology, Eastern Washington State College; C. Gardner Shaw, Department of Plant Pathology, Washington State University; and Paul H. Sunset, Division of Industrial Research, Washington State University.

New Trustees were: Ewart M. Baldwin, Department of Geology, Eugene, Oregon; Randall E. Brown, Pasco, Washington; Phillip C. Johnson, U.S. Forest Service; Rufus Kiser, Centralia College; and John Schwendiman, Department of Agronomy, Washington State University. The Honorary Trustees were: James E. Brooks, President, Central Washington State College; Vernon H. Cheldelin, Department of Chemistry, Oregon State University; and A. E. Weissenborn, U.S. Geological Survey.

1965

The thirty-eighth Annual Meeting of the Northwest Scientific Association was held jointly with the Oregon Academy of Science April 9-10, 1965, at the Sheraton Motor Inn, Portland, Oregon. The Association officers of 1964 carried over in 1965 to the annual meeting. The elected officers for 1966 were Adolph Hecht, Washington State University, President; Rex Boughton, University of British Columbia, Vice President; Bruce V. Ettling, Washington State University, Secretary-Treasurer. Editor: Joseph W. Mills, Washington State University.

The Trustees were: Ewart M. Baldwin, University of Oregon; Randall E. Brown, Pasco, Washington; Royce C. Cox, Potlatch Forests Inc.; Reuben A. Diettert, Montana State University; William Dittrich, Western Washington State College; William K. Ferrell, Oregon State University; Philip G. Haddock, University of British Columbia; Rufus Kiser, Centralia College; Frank Nicol, Eastern Washington State College; John Schwendiman, Washington State University. New Trustees for 1965 were: W. R. Beaufait, U. S. Forest Service; Henry P. Hansen, Oregon State University; William R. Pierce, Montana State University; John R. Roberts, Pacific University; and Edmund E. Tylutki, University of Idaho.

The Honorary Trustees were George Brunzell, Washington Water Power Company, Spokane, Washington; Sherwood Fawcett, Battelle Northwest; Robert Johns, Montana State University.

Dean Henry P. Hansen acted as Moderator on a Symposium on the Columbia River Gorge. Quentin Clarkston, Biology Department, Portland State College, led a Field Trip to the Columbia River Gorge in the vicinity of Multnomah Falls.

Program Chairman was Frank Nicol. One-hundred four papers were read before the six section meetings.

Additional prominent names associated with the program included, William J. Dittrich, Arnold Lahti, Western Washington State College; Ewart M. Baldwin, LeRoy Detling, University of Oregon; Robert M. Storm, Kenneth L. Gordon, D. P. Lavender, Oregon State University; Jon Michael Smith, Seattle University; Samual Arthur, University of Alberta; Charles B. Margach, Pacific University; Norman Anderson, University of Puget Sound; Jack A. Ellingson, Pacific Lutheran University; Roger Olstad, University of Washington; Willis B. Merriam, Washington State University; William G. Wilson, Whitworth College; Philip G. Haddock, University of British Columbia; Daniel Chapelle,

Kenneth W. Kruger, James W. Barrett, Jerry Franklin, U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station; Ronald E. Schmidt, Intermountain Forest and Range Experiment Station; William A. Hunt, Montana State College, Bozeman, Montana; William C. Poulsen, Utah State University; Quentin D. Clarkson, James A. MacNab, Portland State College; James R. Habeck, Montana State University; Earl J. Larrison, University of Idaho; Charles W. Quaintance, Eastern Oregon College; George E. Neff, Bureau of Reclamation; William A. Long, Washington State Department of Natural Resources; Wakefield Dort Jr., University of Kansas.

An Honorary Life Membership was awarded to F. A. Gilfillan. There were no outstanding scientists named for the year 1965. The Secretary reported 320 members in the Association with an annual meeting attendance of one-hundred fifty-one.

A research Grant-in-Aid was awarded to Edward Taylor for radiocarbon dating of plant remains from central Oregon.

The association resumed putting news items in *Northwest Science.* At the October 1965 meeting of the officers and trustees the Hansen report on constitutional changes (first presented in May 1965) was reviewed along with the comments recorded in the minutes of May 1964. The motion to adopt the constitutional changes was seconded and carried. The proposed changes were published in *Northwest Science.*

1966

The thirty-ninth Annual meeting of the Northwest Scientific Association was held jointly with the Montana Academy of Sciences annual meeting on April 15-16, 1966 at the Florence Motor Hotel, Missoula, Montana. The officers of the Association for 1966 were: Adolph Hecht, Washington State University, President; Rex Boughton, University of British Columbia, Vice President; Bruce V. Ettling, Washington State University, Secretary-Treasurer. The Editor of *Northwest Science* was Joseph W. Mills, Washington State University, and the Associate Editor was Edmund E. Tylutki, University of Idaho. Trustees were Ewart Baldwin, University of Oregon; W. R. Beaufait, U. S. Forest Service; Randall E. Brown, Battelle Memorial Institute; Royce C. Cox, Potlatch Forests Inc.; Henry P. Hansen, Oregon State University; Rufus W. Kiser, Centralia College; William R. Pierce, University of Montana; John R. Roberts, Pacific University; John Schwendiman, Washington State University.

New Trustees: James Dick, Weyerhaeuser Company; Reuben Diettert, University of Montana; William Dittrich, Western Washington State College; Frank Nicol, Eastern Washington State College; Richard Walker, University of Washington. Honorary Trustees: C. Clement French, Washington State University; Herbert McKean, Potlatch Forests Inc.

The Annual Banquet Speaker was Harold C. Urey, Nobel Laureate, University of California, San Diego, California, who spoke on, "The Origin of Life." The ten section meetings were coordinated by LeRoy H. Harvey, University of Montana, Program Chairman.

An open house at the Northern Forest Fire Laboratory of the U.S. Forest Service was led by William R. Beaufait.

A representative list of the authors of papers would include: Geoffrey C. Foote, Dennis W. Woodward, Stephen F. Arno, Mark Behan, L. C. Merriam Jr., Donald L. Lodmell, University of Montana; John W. Robinson, C. J. D. Brown, William Johnson, Corale Brierley, A. William Miller, Montana State University; Verle G. Kaiser, S. F. Peterson, Soil Conservation Service; Randall E. Brown, Battelle Northwest; William H. Baker, University of Idaho; Stanley R. Davidson, Western Montana College; W. J. Dittrich, Western Washington College; Richard H. Clem, Whitman College; Rufus W. Kiser, Centralia College; John S. Shrader, Central Washington State College; I. W. Herrick, Mark F. Adams, Willis B. Merriam, Washington State University; Richard B. Walker, David R. M. Scott, K. E. Fry, William A. Long, University of Washington; Michael Newton, Oregon State University; R. V. Boughton, Donald Alford, University of British Columbia; Jerry F. Franklin, James M. Trappe, Robert Pfister, David G. Fellin, Richard F. Schmidtz, David P. Lowery, U.S. Forest Service; William J. Hill, North Dakota Game and Fish Department; Harry W. Anderson, Washington State Department of Game.

One-hundred and thirty-five papers were presented before a registered attendance of one-hundred and ninety-two. Reuben Diettert,

G. Brooks King, N. S. Golding, J. L. Culbertson, Herman Deutsch and G. E. Goodspeed were awarded Honorary Life Memberships in the Association.

The Northwest Scientific Association honored R. A. V. Raff as the Outstanding Scientist of the Year.

We were saddened by the passing of President Rex Boughton, who died of a stroke at his home in Vancouver October 16, 1966. Vice President Julian Barksdale, University of Washington, served as acting president for the remainder of Rex Boughton's term.

1967

The fortieth Annual Meeting of the Northwest Scientific Association was held at Washington State University, Pullman, Washington on April 14-15, 1967. The officers of the Association elected for 1967 were Rex Boughton, University of British Columbia, President; Julian Barksdale, University of Washington, Vice President; Bruce V. Ettling, Washington State University, Secretary-Treasurer. Owing to Rex Boughton's death in October 1966, Vice President Barksdale served as acting president for the remainder of Boughton's term.

Joseph W. Mills, Washington State University, was the Editor of *Northwest Science* and Edmund E. Tylutki, University of Idaho, was Associate Editor.

The Trustees were: W. R. Beaufait, U.S. Forest Service; Royce C. Cox, Potlatch Forests Inc.; James Dick, Weyerhaeuser Co.; Reuben Diettert, University of Montana; William J. Dittrich, Western Washington State College; Henry P. Hansen, Oregon State University; Rufus W. Kiser, Centralia College; Frank Nicol, Eastern Washington State College; William R. Pierce, University of Montana; John R. Roberts, Pacific University; Edmund E. Tylutki, University of Idaho; and Richard Walker, University of Washington.

New Trustees were: Leonard C. Johnson, Washington State University; Ernest Lund, University of Oregon; J. Harry G. Smith, University of British Columbia.

The Honorary Trustees nominated by the Board of Trustees and elected by the vote of the Association were: James Brooks, Central Washington State College; Eugene W. Greenfield, Washington State University; and Ernest Hartung, University of Idaho.

The speaker for the Annual Banquet was David A. Rahm, Department of Geology, Washington State University, who spoke on "Geology from the Air." There were one-hundred and eighty papers presented at the seven section meetings. Jerry F. Franklin, U.S. Forest Service, Corvallis, Oregon was the Program Chairman. The registered attendance was two-hundred and seventy-five and the Association members numbered three-hundred and seventy. At the October Trustees meeting the Secretary-Treasurer, Bruce V. Ettling, reported the page charge for publication in *Northwest Science* is working well and that the editors can promise publication in six months instead of eighteen.

The Symposium on the "Biology of Alder," co-chaired by Jerry F. Franklin and James M. Trappe, U.S. Forest Service, attracted a number of international speakers. Among these were Saburo Murai, Morioka, Japan; Ilmari Schalin, University Helsinki, Finland; Koichi Yamaya, Morioka, Japan; C. Rodriguez-Barrueco, University of Glasgow, Scotland. Other speakers of note on the Alder Symposium included: Fred Johnson, University of Idaho; Robert H. Ruth, U.S.F.S.; B. A. El Hassan and Michael Newton, Oregon State University; William W. Mitchell, Alaska Agricultural Experiment Station, F. C. Ugolini, University of Washington; Robert F. Tarrant, U.S.F.S.; W. B. Bollen, U.S.F.S.; S. P. Gessel, University of Washington; Jack D. Rogers, Washington State University; Robert L. Furniss, U.S. Forest Service; J. Harry G. Smith, University of British Columbia; Richard L. Williamson, U.S. Forest Service; Kenneth J. Turnbull, University of Washington. Other prominent speakers in the general section meetings were: J. Stewart Lowther, University of Puget Sound; William H. Brooks, Gonzaga University; Dale A. Thornburgh, Humboldt State College; Ronald C. Phillips, Seattle Pacific College; W. H. Johnson and Richard Clem, Whitworth College, Spokane; Lorin W. Roberts, Earl J. Larrison, J. Homer Ferguson, Duane S. Andrews, and W. R. Greenwood, University of Idaho; Eugene V. Elliot, Eastern Montana College; Arnold M. Lahti, Western Washington State College; Wayne D. Johnstone, University of British Columbia; Kent R. Richards, Central Washington State College; Vernon S. Robinson, Potlatch Forest Industries,

Lewiston, Idaho; Randall Brown, Battelle Northwest, Richland; H. J. Dahlke, Dennis P. Lavender, Oregon State University; Ernest Lund, University of Oregon, N. Higinbotham, Bruce V. Ettling, J. N. Johnson, Roald Fryxell, Willis B. Merriam, Washington State University; William Long, Department of Natural Resources; Richard B. Walker, Kenneth Reed, University of Washington; Russell E. Clark, Tacoma Community College; Gordon J. Price, Soil Conservation Service.

Honorary Life Membership was granted to C. Clement French, President-Emeritus, Washington State University and S. Vandecaveye, Emeritus, Washington State University, Soil Conservationist.

The outstanding Scientist Awards were made to Grace Howard, University of Washington, and E. S. E. Hafez, Washington State University.

1968

The forty-first annual meeting of the Northwest Scientific Association was held at Central Washington State College March 22-23, 1968. The officers of the Association were Julian Barksdale, University of Washington, President; Bruce V. Ettling, Randall E. Brown, Battelle Northwest, Vice President; Glenn Deitschman, U.S. Forest Service, Secretary-Treasurer; Joseph W. Mills, Washington State University, Editor of *Northwest Science.* The Trustees were: James Dick, Weyerhaeuser Company; Reuben A. Diettert, University of Montana; William J. Dittrich, Western Washington State College; Leonard C. Johnson, Washington State University; Rufus W. Kiser, Centralia College; Ernest Lund, University of Oregon; Frank Nicol, Eastern Washington State College; William R. Pierce, University of Montana; J. Harry G. Smith, University of British Columbia; Richard Walker, University of Washington. New Trustees were: Aaron Baker, Washington State University Western Washington Research Center; Ewart Baldwin, University of Oregon; Ray Broderson, Oregon College of Education; John Shrader, Central Washington State College; Roderick Sprague, University of Idaho.

Ronald Paul, Battelle, Northwest; Emerson Shuck, Eastern Washington State College; and Glenn Terrell, Washington State University, Pullman, Washington, were named as Honorary Trustees.

The General Session speaker at the annual Banquet was Donald R. Johnson, Pacific Northwest Regional Director, U.S. Department of Interior, Fish and Wildlife Service, whose address was "The Outlook for Columbia River Salmon."

The Program Chairman was Roger G. Olstad, University of Washington.

A joint session of the Botany-Zoology and Soil and Water Conservation sections featured a symposium on "The Biological Effects of Pulp Liquor Wastes in Puget Sound." Botany sections were chaired by D. J. Wort and Vladimir J. Krajina, University of British Columbia. Zoology sessions were chaired by J. Homer Ferguson and by Fred W. Rabe, University of Idaho. The Chemistry-Physics sessions were chaired by E. S. Murphy and H. S. Habib, Central Washington State College. Dale R. Comstock of Central Washington State College chaired the Mathematics session. Two of the Forestry sessions were chaired by Robert D. Pfister, U.S. Forest Service, and two other Forestry sessions were under the chair of Michael A. Newton of Oregon State University. William A. Long of the U.S. Forest Service chaired two of the Geology-Geography section meetings, and a third session was under the chair of Edward P. Klucking of Central Washington State College. The Science Education section included three sessions, two chaired by Roger G. Olstad of the University of Washington, the third by Harold C. Jorgensen of Portland State College. The Social Sciences section had three sessions, all chaired by Jane Record of Portland State College. A. S. Baker of Western Washington Research and Extension Center chaired the joint symposium of the Soil and Water Conservation and Botany-Zoology sections, "The Biological Effects of Pulp Liquor Wastes in Puget Sound," and he also chaired one of the specific Soil and Water Conservation sessions. A third Soil and Water Conservation session was chaired by H. H. Wegeleben of the Soil Conservation Service.

The Secretary reported the membership of the Association at three-hundred and fifty-two and the registered attendance at the annual meeting at two-hundred and seventy. One-hundred and seventy-eight papers were presented.

Honorary Life Membership was granted to Adolph Hecht, Botany Department, Washington State University and to William H. Baker, Botany Department, University of Idaho.

Outstanding Scientist awards went to Mark F. Adams, Washington State University; E. Roy Tinney, Washington State University; and J. Hoover Mackin, University of Washington.

1969

The forty-second Annual Meeting of the Northwest Scientific Association was held at Eastern Washington State College March 21-22, 1969. Elected officers of the Association were: Randall E. Brown, Battelle Northwest, President; James Trappe, U.S. Forest Service, Vice President; Glenn Deitschmann, U.S. Forest Service, Secretary Treasurer. The Editor of *Northwest Science* was Joseph W. Mills, Washington State University. The Trustees were: Aaron Baker, Western Washington Research Center; Ewart Baldwin, University of Oregon; Jerry F. Franklin, U.S. Forest Service; Leonard Johnson, Washington State University; Rufus W. Kiser, Centralia College; Ernest Lund, University of Oregon; William Pierce, University of Montana; John Shrader, Central Washington State College; J. Harry G. Smith, University of British Columbia; Roderick Sprague, University of Idaho.

The Trustees were: William Bliss, Edmonds Public Schools; Alfred Halvorson, Washington State University; Martin Kaatz, Central Washington State College; Howard Stien, Whitworth College; D. J. Wort, University of British Columbia.

Honorary Trustees were: Phillip Briegleb, U.S. Forest Service, Portland, Oregon; and Henry Hansen, Oregon State University, Corvallis, Oregon.

The Washington Entomological Society met with the Northwest Scientific Association and contributed five papers, presented at a Friday afternoon session.

Speakers at the General session banquet were: Roald Fryxell and Richard Daugherty of Washington State University. Their topic was, "The Archaeology and Geochronology of the Marmes Rockshelter."

Chairmen of the Symposium, "Columbia River Basalts," were: Ernest Gilmour, Eastern Washington State College, Chairman; and Dale Stradling, Eastern Washington State College, Vice Chairman. A total of thirty papers were presented on this timely symposium.

At the regular section meetings one-hundred ninety-two papers were presented, setting a new record for papers. The Program Chairman was William R. Beaufait, USFS Intermountain Forest and Range Experiment Station, Missoula, Montana. The registered attendance was the highest in the history of the Association, four-hundred and thirty-four. Prominent speakers reading papers at the Section meetings were: A. C. Waters, University of California; Larry Anderson, Whitman College; Richard P. Pharis, University of Calgary, Canada; Dale Thornburg, Humboldt State College; Hugh W. Johnson, Whitworth College; P. L. Wagner, Simon Fraser University; James Trappe, William G. Morris, Pacific Northwest Forest and Range Experiment Station; Harry W. Anderson, Washington State Department of Natural Resources; Randall E. Brown, W. H. Rickard, Battelle Northwest; Aaron Goldman, Gonzaga University; William Beaufait, Intermountain Forest and Range Experiment Station; W. A. Long, U.S. Forest Service; J. W. Bingham, R. C. Newcomb, U.S. Geological Survey; D. H. Henning, Eastern Montana College; D. C. Cheney, Utah State University; D. J. Wort, J. G. Severson, Jr., J. Harry G. Smith, University of British Columbia; C. D. Armsbury, University of Oregon; J. Homer Ferguson, Earl J. Larrison, Loren W. Roberts, University of Idaho; Leonard Levine, Pacific University; B. L. Crowe, Michael Newton, Thomas R. Tanner, D. D. Simons, Oregon State University; R. W. Diettert, R. W. Behan, W. L. Waters, University of Montana; Norman Johnson, D. R. Horner, R. B. Powers, Eastern Washington State College; LeVon Balzer, T. H. Spratlen, G. F. Drake, Western Washington State College; Janet Larson, T. B. Bowen, Central Washington State College; Chris Cramer, University of Puget Sound; Thomas M. Hinckley, Richard B. Walker, Kenneth L. Reed, University of Washington; Robert F. Harwood, Bruce V. Ettling, J. E. Carlson, A. R. Halvorson, Washington State University.

Honorary Life membership was granted to Francis Schadegg, Eastern Washington State College, Cheney, Washington. The outstanding scientists of the year honored by the Association were: Helen Gilkey, Oregon State University; and C. Leo Hitchcock, University of Washington.

The death of Dr. John R. Roberts, longtime member and trustee, and Association president in 1960, was reported.

1970

The forty-third annual meeting of the Northwest Scientific Association was held at the Marion Motor Hotel, Salem, Oregon on March 27-28, 1970. The host institution was Oregon State University, but owing to conflicting meetings the Northwest Scientific Association met at Salem. The Officers of the Association for 1970 were: James Trappe, U.S. Forest Service, President; Lorin Roberts, University of Idaho, Vice President; Glenn Deitschmann, U.S. Forest Service, Moscow, Idaho, Secretary-Treasurer; The Editor of *Northwest Science* was Joseph W. Mills, Washington State University.

The Trustees were: Aaron Baker, Washington State University Western Washington Research Center; Ewart Baldwin, University of Oregon; William Bliss, Edmonds Public Schools; Jerry F. Franklin, U.S. Forest Service; Alfred Halvorson, Washington State University; Roderick Sprague, University of Idaho; Howard Stein, Whitworth College; D. J. Wort, University of British Columbia.

The New Trustees appointed by the Board were: Ray Broderson, Oregon College of Education, Monmouth, Oregon; Ernest Gilmour, Eastern Washington State College; Daniel Henning, Eastern Montana College; Robert Pfister, U.S. Forest Service; Kenneth Waldroff, Division of Continuing Education, Salem, Oregon. Honorary Trustees: Ernest Hartung, University of Idaho; Adolph Hecht, Washington State University; Richard Walker, University of Washington.

A Symposium on "Natural Areas—Needs and Opportunities," was coordinated by William Dittrich, Western Washington State College. Chairmen for the three sessions were: Vladimir Krajina, University of British Columbia; D. H. Henning, Eastern Montana College; and Fred Overly, Bureau of Outdoor Recreation, Seattle, Washington. Herschel Pendell, Oregon State University, served as the Program Director for the eight sections presenting papers.

The Annual Banquet Speakers were the Honorable Robert W. Straub, Treasurer, State of Oregon, who spoke on "Preservation of Natural Landscapes and Environmental Quality, The State Outlook," and the Honorable Thomas S. Foley, U.S. House of Representatives, State of Washington whose address was, "Preservation of Natural Landscapes and Environmental Quality—The Federal Outlook."

Other notable speakers presenting papers on the section meetings were: R. B. Walker, D. R. M. Scott, Grant Sharpe, A. R. Kruckenberg, and F. C. Ugolini, University of Washington; D. P. Lavender, Thomas R. Tanner, Oregon State University; Ernest Lund, University of Oregon; Ronald J. Taylor, Western Washington State College; W. Greene, Eastern Washington State College; D. J. Wort, M. D. Meagher, University of British Columbia; Lorin W. Roberts, Earl J. Larrison, D. R. Johnson, J. H. Ferguson, University of Idaho; H. L. Cook, Southern Oregon College; Reuben A. Diettert, Mark J. Behan, W. R. Pierce, University of Montana; J. W. Padden, University of Victoria; Jacqueline L. Fick, Whitworth College; James M. Trappe, U.S. Forest Service; Royce G. Cox, Vernon S. Robinson, Potlatch Forest Inc.; L. Stewart Lowther, University of Puget Sound; Bruce V. Ettling, Mark F. Adams, Washington State University; Randall E. Brown, W. H. Rickard, Battelle, Northwest; George W. Douglas, University of Alberta; Edgar F. Kleiner, University of Nevada; Jack K. Winjum, Weyerhaeuser Company; A. E. Weissenborn, U.S. Geological Survey; Richard N. Pierson, Washington State Department of Natural Resources; Keith R. Shea, Donald M. Knutson, U.S.F.S Pacific Southwest Forest and Range Experiment Station; William R. Beaufait, Robert D. Pfister, David G. Felin, U.S.F.S. Intermountain Forest and Range Experiment Station; William G. Morris, G. W. Swank, T. D. Anderson, U.S.F.S. Pacific Northwest Forest and Range Experiment Station; Paul Zinke, University of California; R. W. Kiser, Centralia College; A. C. Oehlschlager, L. A. Boland, Simon Fraser University; Philip C. Dumas, Bernard L. Martin, Central Washington State College.

Honorary Life Membership was granted to Joseph W. Mills, Robert R. Tarrant and Bruce V. Ettling.

Outstanding Scientists named by the Northwest Scientific Association for the year 1970 were: Jerry Franklin, U.S. Forest Service, Corvallis, Oregon; Stanley Williamson, Science Ed., Oregon State University; Vladimir Krajina, University of British Columbia, and Rexford Daubenmire, Washington State University.

The Secretary reported a near record membership of four-hundred and seventy-one, exceeded only by 1940 and 1941. Registered attendance at the annual meeting was two-hundred and

seventy-seven and the number of papers presented one-hundred and seventy-seven.

1971

The forty-fourth Annual meeting of the Northwest Scientific Association was held jointly with the Idaho Academy of Science and the Washington State Entomological Society at the University of Idaho, April 16-17, 1971. The officers of the Association were: Lorin Roberts, University of Idaho, President; William Dittrich, Western Washington State College, Vice President; Glenn Deitschmann, U.S. Forest Service, Secretary Treasurer. After many successful years as Editor of *Northwest Science,* Joseph W. Mills, Washington State University, turned over the Editorship to Bruce V. Ettling of the same institution.

The Trustees for 1971 were: William Bliss, Edmonds Public Schools; Ray Broderson, Oregon College of Education; Jerry F. Franklin, U.S. Forest Service; Ernest Gilmour, Eastern Washington State College; Alfred Halvorson, Washington State University; Daniel Henning, Eastern Montana College; Robert Pfister, U.S. Forest Service, Howard Stien, Whitworth College; Kenneth Waldroff, Division of Continuing Education, Salem, Oregon; D. J. Wort, University of British Columbia. The New Trustees appointed to the board were: Levon Balzer, Western Washington State College; Donald Horner, Eastern Washington State College; Otis Maloy, Washington State University; Bernard Martin, Central Washington State College; Alfred Slinkard, University of Idaho.

The Honorary Trustees designated by the Association were: Charles Flora, Western Washington State College; Marshal T. Huntting, Washington State Division of Mines and Geology, Olympia, Washington; Edward Lindaman, Whitworth College, Spokane, Washington.

The Officers of the Idaho Academy of Science were: President, Edmund Tylutki, University of Idaho; Vice-President, Joseph B. Spulnick, Boise State College, Boise; Secretary, Mary Ann Fisher, College of Southern Idaho, Twin Falls; Treasurer, Elmer K. Raunio, University of Idaho.

The Officers of the Washington State Entomological Society were: President, Alan Berryman, Washington State University; President-Elect, Wyatt Cone, W.S.U. Irrigated Agriculture Research and Extension Center, Prosser, Washington; Secretary/Treasurer, Carl A. Johansen, Washington State University.

The Program Chairman was Roderick Sprague, Department of Sociology and Anthropology, University of Idaho, and the Program Editor was Earl J. Larrison, Department of Biological Sciences, University of Idaho.

A record number of papers, two-hundred and ninety-five, were read at the section meetings. Among the prominent authors reading papers were: D. J. Wort, J. Harry G. Smith, M. D. Meagher, University of British Columbia; Thomas M. Hinckley, Richard Walker, Stanley P. Gessel, F. C. Ugolini and D. D. Woolridge, G. E. Goodspeed, University of Washington; Glenn L. Crouch, Donald Knutson, William A. Long, U.S. Forest Service; Kenneth Swedberg, and Bruce Lang, Eastern Washington State College; John Shrader, Donald G. Dittrich, Central Washington State College; Donald B. ZoBell, J. R. T. French and Denis P. Lavender, Oregon State University; John H. Merriam, and C. A. Hofman, Idaho State University; Mark J. Behan, University of Montana; Larry W. Henry, University of Puget Sound; Charles W. Philpot, U.S.F.S. Northwest Forest Fire Laboratory; A. R. Tiedemann, Pacific Northwest Forest and Range Experiment Station; J. M. Finnis, Washington State Department of Natural Resources, J. H. G. Smith, UBC; D. G. Brookins, Kansas State University; Wakefield Dort Jr., University of Kansas; R. P. Pharis, University of Calgary, Canada; Paul Heilman, Crown Zellerbach Co.; R. W. Fonda, Don J. Easterbrook, Western Washington State College; J. Homer Ferguson, Robert Wissmar, Nancy L. Savage, Lorin W. Roberts, A. E. Slinkard, Edmund E. Tylutki, Malcolm M. Furniss, Robert I. Matthews, University of Idaho; Rexford Daubenmire, Adolph Hecht, Bruce V. Ettling, M. A. Adams, Carl Johansen, H. S. Relford, Grant A. Harris, Roald Fryxell, Joseph W. Mills, Washington State University; W. T. Barry, Gonzaga University, Spokane; Harry Kleine, Columbia Basin College, Pasco, Washington; Frederick Young, Evergreen State College; Daniel H. Henning, University of New Mexico; Sherman L. Mclure, Mount Hood Community College; E. Norberg, Idaho Department of Fish and Game; W. A. Johnston, Whitworth College; Richard Clem, Whitman College; Donald R. Jones, Centralia College; Randall E. Brown, Battelle Northwest.

The Northwest Scientific Association honored Julian D. Barksdale, University of Washington; Charles D. Campbell, Washington State University; William K. Ferrell, Oregon State University; and Maurice T. James, Washington State University, with Honorary Life Memberships.

The Outstanding Scientists awards went to Luther S. Cressman, University of Oregon; Stanley P. Gessell, University of Washington; and Thomas M. C. Taylor, University of British Columbia.

1972

The forty-fifth annual meeting of the Northwest Scientific Association was held at Western Washington State College, Bellingham, Washington, on March 23-25, 1972. The Officers elected to serve for the year of 1972 were: William Dittrich, Western Washington State College, President; Richard H. Clem, Whitman College, Vice President; Glenn H. Deitschmann, U.S. Forest Service, Secretary-Treasurer. The Editor of *Northwest Science* was Bruce V. Ettling. Trustees for 1972: Levon Balzer, Western Washington State College; Ray A. Broderson, Oregon College of Education; Ernest H. Gilmour, Eastern Washington State College; Daniel H. Henning, Eastern Montana College; Donald R. Horner, Eastern Washington State College; Otis C. Maloy, Washington State University; Bernard L. Martin, Central Washington State College; Robert D. Pfister, U.S. Forest Service; J. Harry G. Smith, University of British Columbia; Kenneth Waldroff, Division of Continuing Education, Salem, Oregon.

New Trustees: W. Louis Barrett, Western Washington State College; Harry H. Caldwell, University of Idaho; James R. Habeck, University of Montana; Edwin A. Olson, Whitworth College; and Oscar Sziklai, University of British Columbia.

The Honorary Trustees named at the meeting were: Donald Sheehan, Whitman College, Walla Walla, Washington; Edward L. Foubert, Hollister-Stier Laboratories, Spokane, Washington; Glenn Deitschmann, U.S. Forest Service, Moscow, Idaho.

A Symposium on Research on "Coniferous Forest Ecosystems; First Year Progress in the Coniferous Forest Biome, US/IBP" was coordinated by: Jerry F. Franklin, U.S. Forest Service Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon; Dale W. Cole, College of Forest Resources, University of Washington and Richard H. Waring, School of Forestry, Oregon State University.

Co-chairman for all programming and local arrangements were: W. Louis Barrett and Willard A. Brown, Physics Department, Western Washington State College.

A total of 191 papers were presented at the Symposium and the general sections. Prominent speakers were: Stanley P. Gessel, Paul R. Olson, Dale W. Cole, F. B. Taub, Richard B. Walker, D. R. M. Scott, K. L. Reed, B. J. D. Meeuse, F. C. Ugolini, University of Washington; W. Scott Overton, Denis P. Lavender, M. A. Strand, Oregon State University; Robert C. Mitchell, K. H. Baker, Central Washington State College; Dwight Crandall, Tacoma Community College; E. L. Gafford, Battelle Northwest; Donald E. Acheson, University of Puget Sound; Edward B. Wright, Blue Mountain Community College; Warren R. Scott, Wenatchee Valley College, Wenatchee, Washington; R. G. Mitchell, William A. Long, A. R. Tiedemann, U.S. Forest Service; Jerry F. Franklin, G. L. Crouch and M. A. Radwan, U.S.F.S. Pacific Northwest Forest and Range Experiment Station; Mark Johnson, State Board of Community Colleges, Olympia, Washington; Paul A. Eddy, Washington State Department of Ecology; A. S. Baker, Bruce V. Ettling, Mark Adams, Washington State University; R. S. Babcock, Thomas T. Read, Levon Balzer, Western Washington State College; Lorin W. Roberts, Edmund Tylutki, Earl J. Larrison, University of Idaho, Blondel Carleton, University of Portland; Lloyd G. Fritz, Ernest H. Gilmour, D. R. Horner, Eastern Washington State College; R. D. Harr, University of California; J. P. Riley, Utah State University; Mark Behan, W. Selser, University of Montana; W. D. Bliss, Montana State University; Daniel H. Henning, Eastern Montana College, Billings, Montana; V. J. Kraina, D. J. Wort, J. Harry G. Smith, Phillip G. Haddock, O. Sziklai, M. Meagher, T. E. Baker, University of British Columbia.

Honorary Life Membership was granted to Rufus W. Kiser, Centralia College, and Frank Nicol, Eastern Washington State College.

The Association named as outstanding scientist Orlin Biddulph, Washington State University, Pullman, Washington.

The secretary also reported the registered attendance at the 45th annual meeting at 373 and total membership at a record-setting 566.

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W. W. Moyer, Camas, Washington

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Herbert McKean (Potlatch Lumber)

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Richard Walker (UW)

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Edwin B. Lindaman (Whitworth)
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1929	J. A. Kostalek Univ. of Idaho	F. A. Thomson Montana Mines	J. W. Hungate Cheney Normal
1930	F.A. Thomson Montana Mines	C. C. Todd State College of Wash.	J. W. Hungate Cheney Normal

Year	President	Vice-President	Secretary-Treasurer
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1932	I. C. Crawford Univ. of Idaho	T. C. Spaulding Univ. of Montana	J. W. Hungate Cheney Normal
1933	H. R. Flint USFS, Missoula	Thomas Large Spokane	O. W. Freeman Cheney Normal
1934	Thomas Large Spokane	J. W. Hungate Cheney Normal	O. W. Freeman Cheney Normal
1935	W. A. Rockie S.C.S., Pullman	T. A. Bonser Spokane	O. W. Freeman Cheney Normal
1936	J. W. Hungate Cheney Normal	C. W. Hungerford Univ. of Idaho	O. W. Freeman Cheney Normal
1937	C. C. Todd State College of Wash.	J. H. Ramskill Univ. of Montana	O. W. Freeman E.W.C.E.—Elected W. B. Merriam E.W.C.E.—Acting
1938	J. H. Ramskill Univ. of Montana	E. F. Gaines State College of Wash.	W. B. Merriam E.W.C.E.
1939	E. F. Gaines State College of Wash.	F. W. Gail Univ. of Idaho	W. B. Merriam E.W.C.E.
1940	F. W. Gail Univ. of Idaho	J. H. Christ S.C.S., Spokane	W. B. Merriam Oregon College of Educ.
1941	J. H. Christ S.C.S., Spokane	J. W. Severy Univ. of Montana	W. B. Merriam Oregon College of Educ.
1942	J. W. Severy Univ. of Montana	J. B. Appleton Northwest Planning Bd.	J. W. Hungate E.W.C.E.
1943	J. W. Severy Univ. of Montana	J. B. Appleton O.S.S., Wash., D.C.	J. W. Hungate E.W.C.E.
1944	J. W. Severy Univ. of Montana	J. B. Appleton O.S.S., Wash., D.C.	J. W. Hungate E.W.C.E.
1945	J. W. Severy Univ. of Montana	J. B. Appleton O.S.S., Wash., D.C.	J. W. Hungate E.W.C.E.
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1947	J. G. McGivern Gonzaga Univ.	O. W. Freeman E.W.C.E.	G. O. Baker Univ. of Idaho
1948	O. W. Freeman E.W.C.E.	R. F. E. Stier Spokane	L. C. Cady Univ. of Idaho

Year	President	Vice-President	Secretary-Treasurer
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1950	E. E. Hubert Univ. of Idaho	J. L. Culbertson State College of Wash.	L. C. Cady Univ. of Idaho
1951	J. L. Culbertson State College of Wash.	R. A. Diettert Univ. of Montana	L. C. Cady Univ. of Idaho
1952	R. A. Diettert Univ. of Montana	H. P. Hansen Oregon State College	L. C. Cady Univ. of Idaho
1953	H. P. Hansen Oregon State College	L. C. Cady Univ. of Idaho	F. J. Schadegg E.W.C.E.
1954	L. C. Cady Univ. of Idaho	T. J. O'Leary, S.J. Gonzaga Univ.	F. J. Schadegg E.W.C.E.
1955	T. J. O'Leary Gonzaga Univ.	P. E. Church Univ. of Washington	F. J. Schadegg E.W.C.E.
1956	F. B. Farquharson Univ. of Washington	S. Warren Hobbs U.S.G.S., Spokane	W. B. Merriam State College of Wash.
1957	S. Warren Hobbs U.S.G.S.	William K. Ferrell Oregon State College	W. B. Merriam State College of Wash.
1958	William K. Ferrell Oregon State College	Mark F. Adams State College of Wash.	W. B. Merriam State College of Wash.
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1960	John R. Roberts Pacific University	Kenneth E. Hungerford Univ. of Idaho	W. B. Merriam Wash. State Univ.
1961	Kenneth Hungerford Univ. of Idaho	W. B. Merriam Wash. State University	Earl Larrison Univ. of Idaho
1962	W. B. Merriam Wash. State Univ.	W. H. Baker University of Idaho	Earl Larrison Univ. of Idaho
1963	W. H. Baker Univ. of Idaho	Richard Walker Univ. of Washington	Bruce Ettling Wash. State University
1965	F. J. Schadegg Cheney, E.W.C.E.	Adolph Hecht Wash. State Univ.	Bruce Ettling Wash. State University
1966	Adolph Hecht Wash. State University	Rex Boughton Univ. of B.C.	Bruce Ettling Wash. State University
1967	Rex Boughton Univ. of B.C.	Julian Barksdale Univ. of Washington	Bruce Ettling Wash. State Univ.
1968	Julian Barksdale Univ. of Washington	Randall Brown Battelle—Northwest	Bruce Ettling Wash. State University

Year	President	Vice-President	Secretary-Treasurer
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1970	James Trappe U.S.F.S., Corvallis	Lorin Roberts Univ. of Idaho	Glenn Deitschman U.S.F.S., Moscow
1971	Lorin Roberts Univ. of Idaho	William Dittrich W.W.S.C.	Glenn Deitschman U.S.F.S., Moscow
1972	William Dittrich W.W.S.C.	Richard Clem Whitman College	Glenn Deitschman U.S.F.S., Moscow
1973	Richard Clem Whitman College	D. J. Wort Univ. of B.C.	Glenn Deitschman U.S.F.S., Moscow

Recipients of the Outstanding Scientist Award

1961	
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C. P. Ross	
A. L. Anderson	
1966	
R. A. V. Raff	Washington State University
1967	
Grace Howard	University of Washington
E. S. E. Hafez	Washington State University
1968	
Mark F. Adams	Washington State University
E. Roy Tinney	Washington State University
J. Hoover Mackin	University of Washington
1969	
Helen Gilkey	Oregon State University
C. Leo Hitchcock	University of Washington
1970	
Jerry Franklin	U.S. Forest Service, Corvallis
Stanley Williamson	Oregon State University
Vladimir Krajina	University of British Columbia
Rexford Daubenmire	Washington State University
1971	
Luther S. Cressman	University of Oregon
Stanley P. Gessell	University of Washington
Thomas M. C. Taylor	University of British Columbia
1972	
Orlin Biddulph	Washington State University

These awards and annual grants will again be offered in 1989. More details on nomination and application procedures will appear in the November issue of *Northwest Science.*

Upcoming Annual Meeting of the Northwest Scientific Association

The 1989 Meeting of the Northwest Scientific Association will be held at the Tri-Cities University Center in Richland, Washington.

Tentative Schedule of Future Meeting Sites

1990—Oregon State University
1991—Boise State University
1992—Western Oregon University
1993—Eastern Oregon University
1994—University of Oregon

In Memoriam

Friends of C. Clement French will be saddened to learn that he died in March of this year. A chemist by training, he served as the sixth president of Washington State University (1952-1966). He was a longstanding member of Northwest Scientific Association and an Honorary Trustee.

We have just learned of the death of Norman S. Golding at age 95 on 30 August 1984. While a dairy scientist at Washington State University he helped develop "Cougar Gold" cheeses, research that he continued after his retirement in 1955. He was a longstanding member of Northwest Scientific Association and an Honorary Life Member.

Meetings of Interest

Wildland Shrub Symposium

The Shrub Research Consortium is sponsoring the Sixth Wildland Shrub Symposium April 5-7, 1989 at the Holiday Inn, Las Vegas, Nevada. The symposium will address topics in wildland shrub biology and management including cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management. A field trip is planned to the Nevada Test Site of the U.S. Department of Energy. Both contributed (20 minutes) and invited papers will be presented. The proceedings will be published by the USDA Forest Service, Intermountain Research Station. If you would like to present a paper, send a title and abstract by December 15, 1988 to Dr. E. M. Romney, Laboratory of Biomedical and Environmental Sciences, University of California, Los Angeles, 900 Veteran Avenue, Los Angeles, CA 90024.

Whitebark Pine Ecosystems

The U.S. Forest Service, U.S. National Park Service, Montana State University, and the Society of American Foresters are jointly sponsoring a symposium, "Whitebark Pine Ecosystems: Ecology and management of a high mountain resource" to be held 29-31 March 1989 at Montana State University (Bozeman). A concluding field trip into whitebark pine forests near Big Sky Ski Resort is planned. All accepted papers and synopses of posters will be published in the proceedings of the symposium. Please submit title, authors, and a 200-300 word abstract of proposed papers (by 31 October 1988) or posters (by 31 December 1988) to Wyman C. Schmidt, Forestry Sciences Laboratory, Montana State University, Bozeman, Montana 59717 (Tel. 409-994-4852).

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Northwest Science is offered in exchange to other colleges, universities, learned societies, and libraries. Publications sent in exchange should be addressed to Washington State University Library, Technical Services Division, Pullman, Washington 99164-5610, U.S.A.

November 1988 Volume 62, Number 5

Clovis Points in East Wenatchee

NORTHWEST SCIENCE

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Northwest Scientific Association

(Founded 1923)

The Northwest Scientific Association, an affiliate of the American Association for the Advancement of Science, is an association representative of the basic and applied sciences and of social sciences.

Membership in the Northwest Scientific Association, which includes a subscription to *Northwest Science,* is open to individuals for $14 per year ($8 per year for students). Institutional memberships, $40 per year. Sustaining membership, $25 per year for individuals and $100 per year for organizations, institutions, or agencies. Subscriptions are for the calendar year only.

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Kenneth V. Kardong
Department of Zoology
Washington State University
Pullman, Washington 99164-4220

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November 1988 Volume 62, Number 5

NORTHWEST SCIENCE

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Announcements

In this Issue

Clovis peoples, recognized by their manufacture of unique fluted points, represent the earliest distinctive technological tradition in the New World. Historically, the Clovis peoples were the first or at least among the first Americans appearing in the New World around 11,000 years ago. A Clovis site discovered last year in the State of Washington was thus of special interest. Before this discovery, points here-and-there had been found in the Northwest, but this particular site had the artifacts placed in a stratographic sequence. Further, some of the arrow and lance points are the largest ever discovered, anywhere.

Because of this interest, I appreciate the efforts of Dr. Peter Mehringer, who took time from a crowded and busy schedule to write up a brief report of what this site seems to hold so far. His piece appears in our *Research News and Comments* section of this issue.

—editor

Annual Meeting of the Northwest Scientific Association

The 1989 spring meeting of the Northwest Scientific Association (NWSA) will be held March 21-24, 1989, at Tri-Cities University Center, in Richland, Washington. The meeting will be co-sponsored by Battelle Northwest Laboratories, a major non-profit research organization and a Hanford Contractor for the Department of Energy.

The Columbia Basin enjoys an early spring and will be a nice place to spend spring break, especially for those who reside in cold or wet climes. Moreover, it is very nearly in the geographic center of the region and is served by an excellent freeway system. We hope you will consider bringing your family and enjoying the activities we have planned. Visits to the Hanford Reservation are being scheduled to give you the chance to formulate your own opinions of this much criticized operation. We believe you will be surprised at the extent of research conducted in a variety of disciplines under the joint auspices of the Department of Energy, various universities, and Battelle.

This region is characterized as shrubsteppe with cool winters and hot dry summers. Annual precipitation ranges from 6-12 inches across the region but intensive agriculture is carried on with the aid of irrigation.

Two of the prominent physiographic features of the region are the free-flowing Columbia River and Rattlesnake Mountain. The Tri-Cities, located in the heart of Washington wine country, offer numerous wineries within a few minutes drive that welcome visitors to tour their facilities and enjoy sampling their superior products. These and other features should provide added reasons for visiting this part of the Northwest. Our facility (TUC) is located on the bank of the Columbia River in North Richland.

We would remind students attending this year's meeting that registration fees will be waived for NWSA student members who will be presenting papers. In addition, abstracts of all papers presented at the meeting will be formally published as a supplemental issue of *Northwest Science*. We continue to hope that faculty will encourage their students to present results of their research at these meetings.

Call of Applications to the Student Research Grants Awards Committee

Research grants in the amount of $300 will again be awarded to students. The successful recipients will be announced at the spring meeting of the Northwest Scientific Association. Short application forms can be obtained by writing to the Chairman of the Student Research Grants Committee. The completed form should be returned no later than 15 February 1989. The short application form and further information can be obtained from:

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Responses of Small Mammals and Vegetation to Wildfire in Shadscale Communities of Southwestern Idaho

Abstract

During the last 10 years, wildfires have burned 50 percent of the shrub-steppe vegetation in the Snake River Birds of Prey Area. Because of the importance of small mammals as prey for raptors, we assessed the species composition and density of the small mammal populations and the percent cover of vegetative species at burned, partially burned, burned/rehabilitated, and unburned (control) sites. Vegetation on unburned sites consisted primarily of shadscale (*Atriplex confertifolia*) and winterfat (*Ceratoides lanata*) associations, whereas cheatgrass (*Bromus tectorum*) dominated the burned, partially burned, and burned/rehabilitated sites. The deer mouse (*Peromyscus maniculatus*) was the most abundant species on all study sites. More deer mice were captured on partially burned and unburned sites than on burned and burned/rehabilitated sites. Abundance of Townsend's ground squirrels (*Spermophilus townsendii*), as measured by hole counts, was greater on unburned sites than burned ones. This study suggests that wildfires in shadscale habitat reduce small mammal abundance for at least one year after a burn.

Introduction

Numerous studies have assessed the effects of fire on small mammal populations (Ream 1981). Although the majority of these studies were conducted in forested habitat, several recent investigations have focused on the impacts of fire on small mammals in shrub-steppe vegetation (Halford 1981, Hedlund and Rickard 1981, Gano and Rickard 1982, McGee 1982, Keller *et al.* 1983). During the last 10 years, approximately 50% of the shrub-steppe vegetation in the Snake River Birds of Prey Area (BOPA) in southwestern Idaho has burned (Kochert and Pellant 1986). The BOPA supports one of the densest and most diverse assemblages of raptor populations in the world (U.S.D.I. 1979). Because all of the raptor species in the BOPA prey upon small mammals to some extent, fire could affect raptor populations by reducing the rodent prey base through direct mortality and habitat alteration. This paper presents the results of a study to assess the relative abundances of small mammals and percent cover of plant species one year after a wildfire in the BOPA.

Study Area

The study was conducted within the 242,884-ha Snake River BOPA in southwestern Idaho. Prior to recent, extensive range fires, vegetation within the BOPA was shrub steppe dominated by big sagebrush (*Artemisia tridentata*), shadscale (*Atriplex confertifolia*), and winterfat (*Ceratoides lanata*) associations (U.S.D.I. 1979). The Snake River Canyon is the principal physiographic feature of the BOPA with elevation ranging from 770 m in the canyon bottom to 1000 m at the rim. Topography above the canyon is generally flat or slightly rolling with a few isolated buttes. Climate in the BOPA is characterized by hot summers and mild winters; average annual precipitation is 20 cm, most of which occurs in winter.

In July 1985, a wildfire burned 2428 ha on the north rim of the Snake River Canyon (Figure 1). No fires had occurred in the vicinity of this burn for at least 30 years prior to 1985, and vegetation had been dominated by shadscale and shadscale/winterfat associations (U.S.D.I. 1979). Both cattle and sheep had grazed the area for a 75-day period each winter.

During May and June 1986, we identified four range conditions in and adjacent to the burn (Figure 1): burned (B), partially burned (P), burned/rehabilitated (R), and control (C). The partially burned transects were located on the southwestern corner of the burn where the fire burned incompletely and left patches of shrub cover. The burned/rehabilitated sites were those

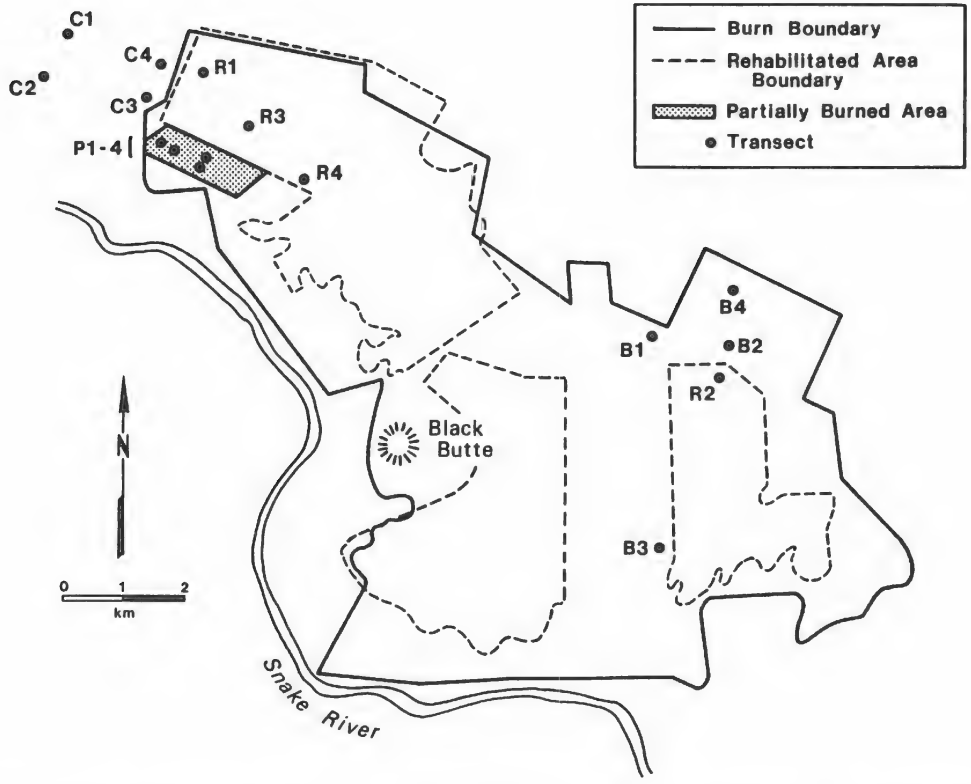

Figure 1. Location of small mammal and vegetation sampling transects on and adjacent to a burned area within the Snake River Birds of Prey Area. B = burned transects; C = control (unburned) transects; P = partially burned transects; R = burned/rehabilitated transects.

areas of the burn that had been drill-seeded in rows spaced 30 cm apart during November 1985 (1860 ha) and March 1986 (240 ha) with a mixture of crested wheatgrass (*Agropyron cristatum* "Fairway" and *Agropyron cristatum* "Siberian"), yellow sweetclover (*Melilotus officinalis*), and fourwing saltbush (*Atriplex canescens*). The control transects were located adjacent to the burn on the west side and consisted primarily of shadscale associations. The burned, partially burned, and burned/rehabilitated sites but not the control sites were rested from grazing in the winter following the fire (1985-86).

Methods

Small mammals were sampled along four 250-m transects randomly located within each of the four range conditions. Each of the 16 transects consisted of 26 trap stations with a 10-m interval between stations. Eight of the 16 transects (B1, B2; P1, P2; R1, R2; C1, C2) were sampled in May with two Museum Special traps and one McGill rat trap at each station. Due to limited catch in rat traps, the other eight transects, which were sampled in June, had only two Museum Special traps per station. Traps were baited with a mixture of peanut butter and whole oats. Following a 2-day prebait period, each transect was trapped for three consecutive days. For each animal captured, information on species, trap station, sex, weight, and reproductive condition was recorded. Males were considered to be in breeding condition if scrotal testes were observed; lactation tissue, noticeable pregnancy, and perforate vaginas were indications of breeding condition for females.

Holes of Townsend's ground squirrels (*Spermophilus townsendii*) and badgers (*Taxidea taxus*) were censused on hole-count transects. Previous work in the BOPA has demonstrated a close correlation between the number of active holes and ground squirrel density ($r = 0.94$, $P = 0.002$) (Nydegger and Smith 1986). Each of the 250-m trapping transects was extended 150 additional meters. We counted all ground squirrel and badger holes in belt transects that were 400 m long and 5 m wide with the transect line serving as the center of the belt. Holes were classified as active if diggings indicated they were used by ground squirrels or badgers during 1986; otherwise holes were recorded as inactive.

Vegetation was sampled on each transect with a point interception frame (Floyd and Anderson 1982). The plant species underneath each point was recorded, and percent cover was calculated independently for each species. Within each transect, five 5-m sections were randomly chosen for vegetation sampling. Thus, a sample unit consisted of one 5-m section of the transect line in which the point frame was used to estimate cover on five consecutive 1-m sections of the transect line. Running means calculated during field sampling indicated that three 5-m sections were adequate to estimate percent cover in the homogeneous B and R transects and that four 5-m sections were sufficient to characterize the more heterogeneous P and C transects. All statistical tests were evaluated at the 0.05 level of significance.

Results

Eighty-two small mammals were captured in 3120 trap nights (Table 1). The deer mouse (*Peromyscus maniculatus*) accounted for approximately 90 percent of the total and was the most common species in all range conditions. Four other species were captured during the study, but their total numbers summed to only seven animals (Table 1). Species richness was highest on the control transects where Great Basin pocket mice (*Perognathus parvus*), a grasshopper mouse (*Onychomys leucogaster*), and a Townsend's ground squirrel were captured in addition to deer mice.

The total number of small mammals captured differed ($\chi^2 = 71.70$, $P < 0.001$) among the four range conditions (Table 1). The same result was observed for deer mice ($\chi^2 = 19.23$, $P < 0.001$). More than twice as many deer mice were trapped on partially burned (P) and control (C) transects than on burned (B) and burned/rehabilitated (R) transects.

TABLE 1. Number of small mammals trapped on transects in burned (B), partially burned (P), burned/rehabilitated (R), and control sites (C) in the Birds of Prey Area (BOPA). Number of small mammals trapped/100 trap nights is given in parentheses.

Species	B	P	R	C	Total
Peromyscus maniculatus	10 (1.3)	31 (4.0)	9 (1.2)	25 (3.2)	75
Perognathus parvus			2	2	4
Dipodomys ordii	1				1
Onychomys leucogaster				1	1
Spermophilus townsendii				1	1
Total	11 (1.4)	31 (4.0)	11 (1.4)	29 (3.7)	82
Trap station nights	312	312	312	312	1248
Trap nights	780	780	780	780	3120

The mean weight of deer mice captured in the study area was 22.4 g ($SD = 5.8$, $n = 59$). There was no difference in the mean weight of deer mice among the B, P, R, and C transects. Additionally, there was no difference in the percentage of deer mice in breeding condition among the C (65%, $n = 20$), P (78%, $n = 22$), and B and R transects combined (56%, $n = 16$). We combined results from B and R transects because of small sample sizes.

The active, inactive, and total number of Townsend's ground squirrel holes differed ($\chi^2 = 19.23$, $P < 0.001$; $\chi^2 = 15.52$, $0.001 < P < 0.005$; $\chi^2 = 46.78$, $P < 0.001$) among the four range conditions (Table 2). More than twice as many total holes were counted on C transects compared to B, P, and R transects. The total number of badger diggings was also different ($\chi^2 = 26.83$, $P < 0.001$) among the four range conditions (Table 2). Again, the greatest number of diggings was observed on C transects.

TABLE 2. Number of ground squirrel holes and badger diggings counted on transects in burned (B), partially burned (P), burned/rehabilitated (R), and control (C) sites in the Birds of Prey Area (BOPA).

Species	B	P	R	C	Total
Townsend's Ground Squirrel					
Active	9	19	7	29	64
Inactive	12	12	7	36	67
Total	21	31	14	65	131
Badger					
Active	4	2	1	7	14
Inactive	13	8	10	31	62
Total	17	10	11	38	76

Vegetation on C transects was dominated by a 14 percent cover of shadscale and 7 percent cover of winterfat (Table 3). Important grasses were bottlebrush squirreltail (*Elymus elymoides*) and cheatgrass (*Bromus tectorum*). In contrast, B and R transects had little or no shadscale and winterfat cover, but considerably more cheatgrass (26 and 14%, respectively) and no squirreltail. B, P, and C transects were characterized by 22 percent bare ground, whereas estimates of bare ground in the R transects averaged 54 percent (Table 3). Cover values for litter ranged from 16 percent in the R transects to 34 percent in B transects. The C transects contained the greatest number of plant species (9); the P transects contained the greatest number of exotic species (5). B and R transects were devoid of any moss or lichen cover.

TABLE 3. Mean percent cover values for vegetation sampled on transects in burned (B), partially burned (P), burned/rehabilitated (R), and control (C) sites in the Birds of Prey Area (BOPA). Sample sizes (n) are given in parentheses.

Species	B (n=12)	P (n=16)	R (n=12)	C (n=16)
Shrubs				
Atriplex confertifolia	x[1]	6	—	14
Ceratoides lanata	x	—	—	7
Artemisia spinescens	—	—	—	x
Dead Shrub	4	9	—	5
Grasses				
Elymus elymoides	—	2	—	5
Poa sandbergii	—	—	—	3
Bromus tectorum[2]	26	9	14	5
Vulpia sp.	—	—	x	x
Forbs				
Sisymbrium loeselii[2]	3	3	x	2
Descurainia sophia[2]	5	3	6	x
Chenopodium leptophyllum	—	x	x	—
Salsola kali[2]	x	x	—	—
Halogeton glomeratus[2]	—	x	—	—
Plagiobothrys sp.	—	—	x	—
Amsinckia retrorsa	—	—	x	—
Bare Ground	22	22	54	22
Litter	34	26	16	20
Moss	—	2	—	7
Lichen	—	—	—	2
Total number of species[3]	6	8	7	9

[1]x = species present but mean percent cover < 1.0.

[2]Species introduced to North America.

[3]Does not include moss, lichen, bare ground, litter, or dead shrub.

Discussion

The response of rodent populations to fire depends on the species involved, the vegetation type, and the type and intensity of the burn. The present study was conducted one year after an intense wildfire burned 2428 ha of shrub-steppe vegetation in the Snake River BOPA. Prior to the fire, vegetation on the burned transects was dominated by shadscale (10% canopy coverage) and cheatgrass (3% canopy coverage; U.S.D.I., unpubl.). Our post-fire vegetation sampling showed that shadscale cover had decreased to less than 1 percent in burned and burned/rehabilitated sites and that cheatgrass had increased to approximately 26 percent in burned and 14 percent in burned/rehabilitated sites.

The number of small mammals captured during this study was low for all species, except deer mice, at both burned and control sites. The number of deer mice captured at burned and control sites was also low when compared with other studies. An earlier BOPA study (U.S.D.I. 1979) reported relative densities (number of animals trapped/100 trap nights) of deer mice in shadscale ranging from 4.2-23 for the years 1975-1978. In "depleted" (heavily grazed) and "healthy" stands of shadscale in south-central Idaho, Larrison and Johnson (1973) reported relative densities of deer mice to be 14 and 7.8, respectively. Relative density of deer mice in this study (Table 1) was 3.2 (animals/100 trap nights) in grazed shadscale habitat (C transects) and approximately 1.2 in cheatgrass stands (B and R transects).

Both the number of deer mice and the total number of small mammals captured were lower at burned and rehabilitated sites than at partially burned and control sites. This finding is in agreement with other studies in similar habitat. Rogers and Hedlund (1980) found fewer deer mice in a cheatgrass community compared to needle-and-thread grass (*Stipa comata*) and sagebrush/juniper (*Artemisia tridentata/Juniperus occidentalis*) communities. Gano and Rickard (1982) reported three times as many small mammals in shrub-dominated unburned areas as cheatgrass-dominated burned areas. Larrison and Johnson (1973) commented that cheatgrass stands in south-central Idaho supported only a few pocket mice and deer mice.

Counts of Townsend's ground squirrel and badger holes revealed that these two species also had lower numbers in burned (B, R, and P) sites than control sites (Table 2). A previous live-trapping study of Townsend's ground squirrels in the BOPA (Smith and Johnson 1985) concluded that densities did not differ among several different vegetation types including cheatgrass. Smith and Johnson (1985) did note, however, that densities of ground squirrels in shadscale were too low to effectively study them there. Counts of Townsend's ground squirrel hole numbers in the BOPA, conducted at the same time as our study, have indicated a decrease in squirrel holes in all habitats between 1982 and 1986 (Peterson and Yensen 1986). These decreases were even greater in burned areas than in unburned ones.

Counts of inactive holes may be a reflection of pre-fire squirrel densities. Control transects had greater numbers of inactive holes than burned transects. However, it is not known whether soil movement following fire destroys inactive holes in burned areas. Therefore, we cannot conclude that fire is the primary factor responsible for lower hole counts in burned areas.

This study suggests that wildfire in shadscale habitat reduces small mammal abundance one year after a burn. In burned areas dominated by cheatgrass, two factors may limit small mammal populations. First, the loss of shrub cover may result in increased predation of small mammals (Gano and Rickard 1982, Nydegger and Smith 1986), particularly in the BOPA where dense raptor populations exist. Second, thick stands of cheatgrass may impede small mammal movements which in turn may affect breeding success and population size (Gano and Rickard 1982). Both of these factors could be responsible for the observed decreases in abundance of deer mice and Townsend's ground squirrels, although other factors such as a change in available food resources could also be important.

Acknowledgments

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Activity and Diet in Seepage-Dwelling Coeur d'Alene Salamanders (*Plethodon vandykei idahoensis*)

Abstract

Through 1985 and 1986 activity and diet in a seepage-dwelling population of the Coeur d'Alene salamander (*Plethodon vandykei idahoensis*) were studied in northwestern Montana. Activity was almost entirely nocturnal and had a weak, but significant positive correlation with nighttime substrate temperature. During June, July, and August, activity was periodically reduced and had a weak, but significant negative correlation with daytime substrate temperature and a strong, negative correlation with the number of days since the last rain. *Plethodon v. idahoensis* was active in free water and aquatic prey species were found in its diet. This salamander exploits very wet microhabitat where it is insulated from climatic extremes. These habits may have contributed to the continued survival of *P. v. idahoensis* in a region that once had a milder climate and apparently supported a richer plethodontid fauna.

Introduction

Van Dyke's salamander (*Plethodon vandykei*) is unusual among its congeners in its often close association with free water. Although found in forest debris or damp talus far from such aquatic situations (Slater 1933, Slater and Slipp 1940, Nussbaum *et al.* 1983), it is commonly encountered along streamsides and in the splashzones of seepages and waterfalls (Nussbaum *et al.* 1983). *Plethodon vandykei* enters streams to avoid capture and has been referred to as the most aquatic *Plethodon* (Brodie 1970).

The ecological importance of this species' preference for very wet microhabitat may vary geographically. It has been implied that such preference reduces competition between the Washington salamander (*P. v. vandykei*) and more terrestrial sympatric *Plethodon* in the mild, damp climate of western Washington (Brodie 1970). In the eastern part of the species' range, the common association of the Coeur d'Alene salamander (*P. v. idahoensis*) with streams and splashzones is probably due to the hydric and thermal stability of these situations (Hynes 1970) in a climate apparently harsher than that associated with other western *Plethodon* (Nussbaum *et al.* 1983). [Since the taxonomy of this species lacks a consensus (Frost 1985), we use the nomenclature of Lowe (1950) which recognizes two subspecies.] Such stability is important to plethodontids because they require moist skin for respiration, a trait restricting their surface activity in desiccating conditions (Feder 1983). The ability to be surface-active would appear to be crucial to *Plethodon* since suitable prey may be largely inaccessible below ground (Jaeger 1972, Fraser 1976).

Our study has centered around a seepage-dwelling population of *P. v. idahoensis* in northwestern Montana. Through seasonal censusing, we have attempted to identify and assess environmental factors that limit the surface activity of this salamander in a type of microhabitat with which it is very commonly associated. Our study site and method have permitted observation of the salamander's hydrophilic behavior and we have also analyzed its diet.

Study Site and Methods

The study area is on the north slope of the Cabinet Mountains in Lincoln County, Montana, at 600 m elevation. The six perennial seepages we used occur along an 800 m stretch of an easement cut in 1924 for U.S. Highway 2 and the Northern Pacific Railroad. The easement is approximately 30 m above the Kootenai River along the walls of a steep gorge forested in *Pseudotsuga menziesii/Symphoricarpos albus* and *Thuja plicata/Clintonia uniflora* habitat types (Pfister *et al.* 1977). Salamanders were first discovered

here in 1962 (Teberg 1964). The springs are of the fracture type (Fetter 1980), with water emerging from tabular beds of Belt quartzite (Winston and Woods 1986). Temperature of emergent water in the springs varies from 4.2°C to 9.4°C annually. The three largest seepages, where we made salamander counts, involve 3 to 9 m high rockfaces down which spring water streams and cascades. The resulting splashzones comprise ~250 m^2 of vertical, bryophyte-covered rock. At the base of the rockfaces, rubble has accumulated and the splashzones extend horizontally 1 to 3 m. Water from the seepages fills a continuous 1 m wide ditch beside the highway.

Periodic salamander counts were made during 19 all-night and 14 half-night censuses performed from 30 May to 10 November 1985, and from 8 March to 26 October 1986. All-night censuses were conducted to determine qualitatively the diel activity pattern of the salamanders. Counts began 4 hours before sunset and were repeated once every 2 hours until 4 hours after sunrise. Half-night censuses were performed using the same method as above except that counts were terminated 4 hours after sunset.

Seven substrate temperatures were taken during each count using alcohol thermometers. These measurements were made at stations in the seepages established for their proximity to large numbers of salamanders. Three temperatures were taken from the vertical rockfaces, three from substrate at the base of the rockfaces, and one from pooled water in the highway ditch. A mean substrate temperature was calculated for each salamander count.

Starting at sunset, salamanders were counted with the aid of a flashlight. The counting procedure involved walking between 1 and 3 m from the rockface, recording every salamander visible on the ground and on the rockface up to 3 m above ground level. The entire rockface encompassing the three seepages was checked for salamanders. Care was taken to use the same path and method during each count. In all counts except those made during the first census on 30 May 1985, the substrate associated with each salamander was recorded.

For our analysis of salamander activity and distribution within the seepages, data from counts made 4 hours after sunset were arbitrarily used. Census data from 1985 and 1986 were pooled. Activity levels were compared to mean substrate temperatures from 2 hours before and 4 hours after sunset on the same census visit. Activity levels were also compared to rainfall data obtained from a U.S. Forest Service weather station 10 km from the study site. Spearman rank correlations were calculated with a 1983 SPSS, Inc. software package.

Salamander stomach contents were sampled 10 times from 15 May 1985 to 11 October 1985 and three times in 1986, twice in April and once in May. Two to seven salamanders were collected from each of the six seepages at night, after the last count in a census visit. Following collection, salamanders were kept on ice until their stomach contents were removed, not more than 5 hours later. Salamanders were anesthetized with MS-222 and their stomach contents removed using the flushing method of Legler and Sullivan (1979). We observed no ill effects on salamanders subjected to this procedure, and released each individual at night within 1 m of its site of capture. Prey items obtained from stomach samples were identified using Pennak (1978), Borror *et al.* (1981), and Merritt and Cummins (1984). Stomach content data from 1985 and 1986 were pooled for analysis.

Results

Salamander activity in the Kootenai seepages was reduced in the fall and spring (Figure 1) and had a weak, positive correlation with nighttime substrate temperature ($r_s = 0.3935$, $N = 30$, $P = 0.016$). Much of the spread in a plot of this correlation can be attributed to reduced salamander activity on six summer nights, five in June and July of 1985 and one in August 1986. If these nights are left out of the analysis, the positive correlation between peak salamander activity and nighttime substrate temperature is high ($r_s = 0.7119$, $N = 24$, $P < 0.001$). These six nights were associated with locally high daytime temperatures and the absence of rain. During June, July and August only, peak salamander activity had a weak, negative correlation with daytime substrate temperature $r_s = -0.4871$, $N = 16$, $P = 0.028$) and a strong, negative correlation with the number of days since the last rain ($r_s = -0.8082$, $N = 16$, $P < 0.001$).

During the last 1985 visit to the site on 10 November, the area within the seepages was

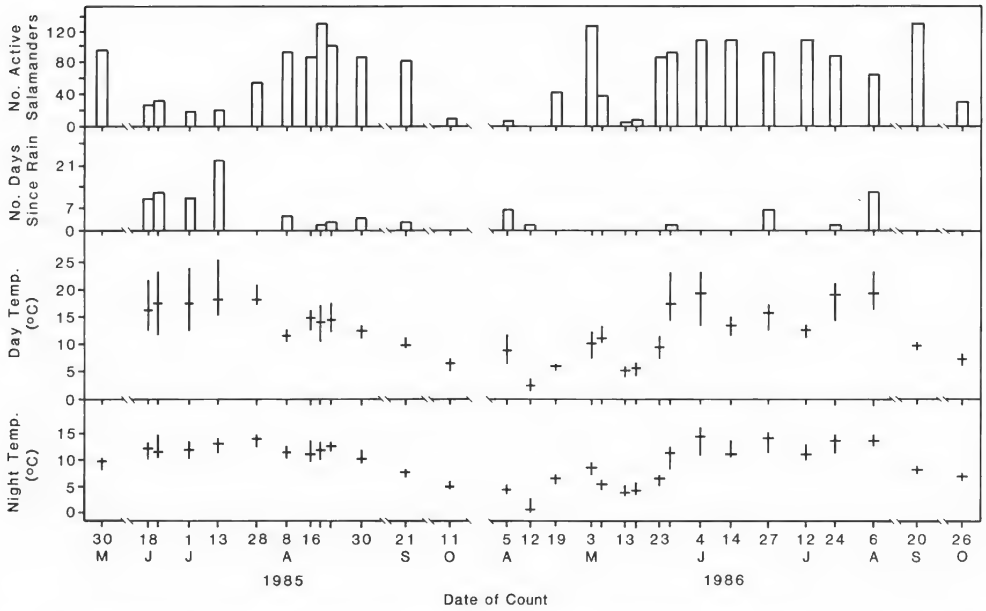

Figure 1. Activity of *Plethodon vandykei idahoensis* 4 hours past sunset and some environmental correlates during ice-free periods in the Kootenai Gorge seepages, Lincoln Co., Montana. Only the first date is given for counts made on consecutive days. Substrate temperature means and ranges represent data taken 4 hours past sunset (night), and 2 hours before sunset (day). No day temperatures were obtained on 30 May 1985.

about 90 percent ice-covered and no salamanders were observed. On 8 March of the following year, when conditions were similar, one salamander was observed at sunset through a hole in the ice where 4.4°C water was flowing over the soil. By 21 March, about 60 percent of the area within the seepages was still ice-bound and four salamanders were counted 4 hours after sunset. All water at the site was completely thawed by 4 April 1986. No visits were made to the site after 26 October 1986, but the seepages were again ice-bound by 25 November (N. Lamorie, pers. comm.).

Salamander activity was almost entirely nocturnal. Five of 11 observations of day-active salamanders occurred while rain was falling from completely overcast skies; during the other six days the sky was clear and no rain had fallen for 24 hours. Salamander activity in 11 of the 19 all-night censuses appeared fairly constant; similar numbers of salamanders were counted both early and late at night. During the other eight all-night censuses, mean substrate temperatures dropped below 4.0°C and activity was heaviest during early evening, tapering off as temperatures fell.

Of the total number of salamanders (n = 1950) observed during this study 4 hours after sunset, 1132 (58.1%) were on vertical rockfaces, 779 (40.0%) were in the rubble at the base of the rockfaces or on various substrates along the side of the highway ditch, 36 (1.8%) had entered the pooled water of the highway ditch, and three (0.2%) were climbing plants. Salamanders observed in the pooled water of the ditch were always within ~10 cm of the pool edge and none were completely submerged. *Plethodon v. idahoensis* must swim voluntarily because individuals were periodically seen on rocks in the middle of the pools. We commonly saw salamanders, especially those on rockfaces, within thin sheets of streaming water (hydropetric areas), but none were observed in rapidly flowing water.

Although we did not mark individuals, our observations indicate a considerable amount of movement by some salamanders. These appeared to travel distances of ~5 m during the night,

crossing the highway ditch and patrolling the edges of its pools. Salamanders remained within the splashzones except on nights when the surrounding ground was saturated by rain. At such times individuals were found up to 10 m from the splashzones and were occasionally observed on the highway.

The prey of *P. v. idahoensis* were mostly insects (Table 1) and many of these were aquatic: immatures of Ephemeroptera, Plecoptera, Trichoptera, Coleoptera, and many Diptera, as well as Gerridae in all stages of development. Diptera larvae, especially two species of *Caloparyphus* (Stratiomyidae), were numerically and volumetrically the most important prey. Adult salamanders took mostly Diptera larvae (26.1%) and adults (11.8%), Collembola (9.7%), Homoptera (6.6%), Hemiptera (6.6%), Hymenoptera (5.9%), Acarina (5.3%), and Coleoptera adults (4.8%). These prey were found in >20 percent of all adult stomachs except for Homoptera (19.7%) and Hemiptera (13.9%) and comprised 76.8 percent of all items. The numerical importance of Hemiptera was inflated by the appearance of 25 nymphal waterstriders in the stomach of one individual.

TABLE 1. Prey of 122 adult (≥4.5 cm SVL) *Plethodon vandykei idahoensis* from the Kootenai Gorge seepages, Lincoln Co., Montana. Percent occurrence denotes the numerical proportion of the total prey (n = 863) ingested.

Prey	Percent Occurrence
COLLEMBOLA	9.7
EPHEMEROPTERA NYMPHS	0.6
PLECOPTERA ADULTS	0.8
PLECOPTERA NYMPHS	2.8
PSOCOPTERA	0.2
HEMIPTERA	6.6
Gerridae	5.4
Other	1.2
HOMOPTERA	6.6
COLEOPTERA ADULTS	4.8
Staphylinidae	2.0
Elateridae	0.7
Cantharidae	0.3
Curculionidae	0.5
Other	1.3
COLEOPTERA LARVAE	1.9
Dytiscidae	1.3
Hydrophilidae	0.3
Other	0.2
TRICHOPTERA ADULTS	3.2
TRICHOPTERA LARVAE	3.5
Rhyacophilidae	0.8
Limnephilidae	1.0
Lepidostomatidae	0.5
Brachycentridae	0.3
Other	0.8
LEPIDOPTERA ADULTS	0.3
LEPIDOPTERA LARVAE	1.3
DIPTERA ADULTS	11.8
Chironomidae	3.7
Mycetophilidae	1.7
Other	6.4
DIPTERA LARVAE	26.1
Tipulidae	4.9
Psychodidae	4.9
Dixiidae	0.5
Chironomidae	6.0
Stratiomyidae	8.1
Other	1.7
HYMENOPTERA ADULTS	5.9
Ichneumonidae	2.7
Formicidae	1.6
Other	1.6
DIPLOPODA	0.3
ACARINA	5.3
ARANEA	3.4
PHALANGIDA	0.1
GASTROPODA	2.1
Lymnaidae	1.2
Other	0.9
OLIGOCHAETA	2.7

Discussion

Our observations of *P. v. idahoensis* in hydropetric areas and in pooled water indicate this salamander is well adapted to life in splashzones. This adaptation is reflected in the importance of semiaquatic and aquatic prey in the salamander's diet (Table 1). The ability of *P. v. idahoensis* to live in very wet microhabitat, such as that of the Kootenai seepages, enables it to occupy equable conditions in a relatively severe climate. Plethodontids are restricted in activity, and thus in their foraging ability, by low humidity, low substrate moisture, and high temperatures (Feder 1983, Feder and Londos 1984, Keen 1984). Seepage areas provide cool water (Hynes 1970) and splashzones moisten substrates while providing locally high humidity (Huheey and Brandon 1973). Conditions in the Kootenai seepages that are favorable to plethodontids center around local bedrock fracturing. This fracturing not only results in the emergence of spring water (Fetter 1980), but also provides daytime retreats for the salamanders and is apparently deep enough for refuge from freezing during winter.

Despite favorable conditions within the seepages, salamander activity is reduced during cold weather. In late fall, winter, and early spring, movement out of fractures may be restricted by the ice that covers seepage surfaces. At other times activity appears to be reduced by substrate temperatures dropping to ~4°C. Periods of these low, nonfreezing temperatures occur primarily in April, May, October, and November. The thermal stability of spring water (Hynes 1970) probably enables seepage-dwelling *P. v. idahoensis* to be active on colder nights than *P. v. idahoensis* residing in other types of microhabitat.

Thermal and hydric stability result in greater midsummer activity of *P. v. idahoensis* in the splashzones of seepages and waterfalls than in other situations. Nussbaum *et al.* (1983) reported that forest and talus populations remain largely underground from June to September, a pattern typical of plethodontid salamanders in western North America (Houck 1977). Reductions in salamander activity during the summer months do occur in the Kootenai seepages and are accompanied by high daytime temperatures and lack of rain (Figure 1). These reductions are periodic, however, and activity can be observed throughout the summer. The annual activity cycle of seepage-dwelling *P. v. idahoensis,* thus appears to be more similar to the cycle of eastern plethodontids (Taub 1961, Houck 1977) than to that of most western forms.

Midsummer reductions of salamander activity in the seepages may stem from a heating of substrates during the day, which forces salamanders into the deeper fractures of the rockface. This factor does not greatly affect the number of night-active salamanders on a short term basis, as indicated by the weak correlation between daytime substrate temperatures and summer salamander activity. Over a long period of little rain and high daytime temperatures, however, it appears that the salamanders move underground and relatively few emerge at night. Evidence for such movement includes the negative correlation of summer salamander activity to lack of rain, the high daytime substrate temperatures associated with periods of little rain (Figure 1), and the report by Lynch (1984) that in midsummer, salamanders in the Kootenai seepages are relatively difficult to find under surface debris during the day. Vertical migration of North American plethodontids to avoid heat has been recorded in field experiments (e.g., Taub 1961), but such behavior is rarely observed in the field because these salamanders may only infrequently encounter unsuitably high temperatures in the moist situations they inhabit (Feder 1983).

Nocturnal activity such as we observed in *P. v. idahoensis* is common in plethodontids (Hairston 1949) and is probably associated with endogenous rhythms (see Ralph 1957, Adler 1970). These rhythms enable organisms spending a portion of their day underground to emerge at appropriate times without environmental cues (Enright 1970). Selection for nocturnal activity may come from daytime predators (Semlitsch and Pechmann 1985) such as birds, which can be efficient at capturing salamanders (Brandon and Huheey 1975, Wilson and Simon 1985). Plethodontids can also avoid heat or desiccation via nocturnal activity (Feder 1983), and under favorable conditions of light, temperature, and moisture some species may be active during the day (Hairston 1949). However, in the Kootenai seepages we observed little diurnal activity, even on cloudy, cool days.

Conditions within splashzones that provide suitable habitat for *P. v. idahoensis* also help sustain populations of the invertebrates upon which salamanders feed (Hynes 1970, Huheey and Brandon 1973, Keen 1979). That we observed *P. v. idahoensis* partly submerged in standing water, plus the occurrence of waterstriders and Collembola in the diet, indicate this salamander is able to forage upon neustonic organisms (Scott 1956, Usinger 1956). It is unclear how the salamander takes benthic prey but most of these were apparently captured in hydropetric areas or in the highly saturated soil within the splashzones. Such areas support populations of snails and oligochaetes, as well as the immatures of some Ephemeroptera, Plecoptera, Trichoptera, Coleoptera, and Diptera (Hynes 1970, Pennak 1978, Teskey 1984). Some of the aquatic organisms in the diet of *P. v. idahoensis* may represent instances of these invertebrates leaving the water. A few benthic insects, such as the larvae of some Trichoptera, are known to emerge from water to forage (Erman 1981) and many immature aquatic insects leave the water before transforming into adults (Hynes 1970). The majority of the Plecoptera nymphs taken by salamanders in this study were in their last instar and were, therefore, likely captured on land prior to their final molt (see Hynes 1976).

The diet of *P. v. idahoensis* in the Kootenai seepages is unusual for that reported in western *Plethodon.* The diets of the Del Norte salamander (*P. elongatus*), the Larch Mountain salamander (*P. larselli*), the Jemez Mountains salamander (*P. neomexicanus*), the Siskyou Mountain salamander (*P. stormi*), and the western red-backed salamander (*P. vehiculum*), lack aquatic prey (Dumas 1956, Bury and Johnson 1965, Altig and Brodie 1971, Reagan 1972, Nussbaum *et al.* 1983), probably because of the terrestrial habits of these species. Of all western *Plethodon* only Dunn's salamander (*P. dunni*) is commonly present in microhabitat similar to that of *P. vandykei.* The former has been collected in water-soaked areas and along streamsides (Stebbins 1951, Dumas 1956, Brodie 1970), and like *P. vandykei* (Brodie 1970), may take to water to avoid danger (Stebbins 1951). Reports on the diet of *P. dunni* by Dumas (1956) and Altig and Brodie (1971) do not mention aquatic prey. While this may indicate less aquatic habits for *P. dunni* than *P. vandykei,* it is possible that the salamanders used in these two studies were from populations not associated with free water.

There is a strong resemblance between the diet of *P. v. idahoensis* in the Kootenai seepages and that of adults of some species of *Desmognathus* that live in similar microhabitat in eastern North America (Burton 1976, Keen 1979). This similarity probably stems from a shared propensity for entering water (see Bishop 1943, Hairston 1949), at least to the extent required to take neustonic and hydropetric prey. *Plethodon v. idahoensis* may thus be regarded as an ecological counterpart to the desmognathine and hemidactyliine plethodontid species that occupy a semi-aquatic adaptive zone (Wake 1966) unexploited by most *Plethodon.*

Given the paucity of behavioral and dietary information on hydrophilic species of *Plethodon* such as *P. dunni,* it is unclear whether the extremely close association between *P. vandykei* and free water is unique for the genus. However, *P. vandykei* has a unique disjunct distribution (Nussbaum *et al.* 1983) which may attest to the importance of such an association. It is possible that an ability to reside in the insulation of very wet microhabitat has contributed to the persistence of this salamander in the northern Rocky Mountains; a region with severe winters and dry summers (Baily 1980, Nussbaum *et al.* 1983), where drastically changing environmental conditions presumably eliminated an earlier, richer plethodontid fauna (Thurow 1968, Tihen and Wake 1981).

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Results of a Mountain Goat Transplant along Lake Chelan, Washington

Abstract

In an attempt to increase the population, marked mountain goats (*Oreamnos americanus*) (n = 44) were transplanted from Olympic National Park to Lake Chelan in the Cascade Mountains of Washington in 1983 and 1984. To evaluate the success and integration of these individuals into the population, we compiled sightings of the marked mountain goats. Twenty-seven individuals were resighted a total of 95 times following release. Distances moved by released males and females were not significantly different ($P > 0.05$). Males traveled an average of 19.8 linear km (SE = 10.2) from release sites, compared to 13.9 km (SE = 15.4) for females. Released kids were never seen beyond 5 days after release. Released goats occupied vacant goat range, joined native goat bands within the drainage, or left the drainage. Transplanted goats intermixed with native goats to potentially introduce genetic variability. A minimum of ten kids were born to transplanted nannies during the three summers after initial release. This study showed that collars and ear tags are both inexpensive and effective methods to mark mountain goats for study over an extended period. Further, because many transplanted mountain goats intermixed and bred with members of the local population, the transplant should be considered successful.

Introduction

Mountain goats (*Oreamnos americanus*) were numerous along Lake Chelan in central Washington until the late 1970's (Johnson 1983). During the 1960's and 1970's, as many as 100 goat hunting permits were issued in the three units bordering the lake. By the late 1970's goat populations had declined sharply. The only historical goat population data available for this area are from Washington Department of Wildlife (WDW) once-per-winter, randomly scheduled (November-April) surveys conducted from a boat during 25 of the 30 winters from 1953-54 through 1982-83. Examination of these data showed a negative rate of increase (Caughley 1977) of $\bar{r} = -0.07$ during that period. Because of this decline, and low kid:adult ratios reported on goat hunter harvest questionnaires, goat hunting was closed in the Stehekin Valley and south shore units after the 1978 season and in the north shore unit after the 1980 season in an effort to increase goat numbers. Data are not available to assess effects of the hunting closure because WDW discontinued their surveys after the 1982-83 winter and our later surveys were more intensive (12/winter) and results are not comparable. Also, goat hunter report cards were no longer obtained from these goat units to gather comparable data on kid to adult ratios.

Mountain goats were introduced into the Olympic Mountains in western Washington (prior to the creation of Olympic National Park) from Alaska and Alberta in the 1920's (Stevens and Driver 1978). Much of the Olympic Mountains was later included within the boundaries of Olympic National Park. By the early 1980's, the goat population within the park reached levels which prompted park officials to reduce goat numbers to preserve habitat quality (Houston *et al.* 1986). As a part of the park's reduction program, goats were captured and transplanted by WDW to other areas.

During the summers of 1983 and 1984, goats were transplanted from Olympic National Park to the shores of Lake Chelan in an attempt to increase that goat population. Expected benefits of the transplant identified in the U.S. Forest Service environmental assessment were to:

1) increase goat numbers in suitable goat habitat which was unoccupied or underpopulated (compared to past WDW surveys), and

2) possibly increase the reproductivity of the Lake Chelan goat population by introducing genetic variability from the Olympic Mountains goat herd.

Although mountain goats have been transplanted into many areas (Guenzel 1980), little information is available concerning the movements and interactions of the released individuals. We evaluated the Lake Chelan transplant to determine:

1) transplanted goats' affinity to release sites,

2) transplanted goats' association with native goats, and

3) the number of offspring produced by transplanted goats.

Study Area

Lake Chelan lies on the east slope of the Cascade Mountains in northern Chelan County in central Washington (Fig. 1). The lake is approximately 1.6 km wide and 82 km long, extending from the Columbia River breaks to the high Cascades. The lake's maximum elevation is 335 meters m.s.l. and mountain peaks exceeding 2,400 meters m.s.l. overlook the lake.

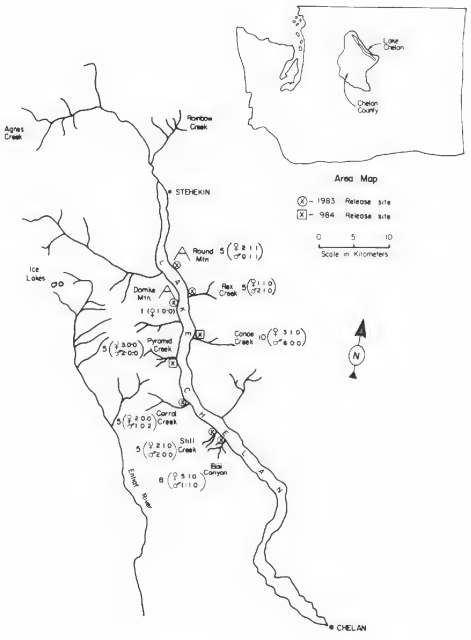

Figure 1. Mountain goat transplant area along Lake Chelan, Washington, 1983-84 (numbers of released goats indicated in parentheses by age, i.e., adults: yearlings:kids).

All of the release sites were along the shores of the northwest half of Lake Chelan within the Wenatchee National Forest. Vegetation zones within this area include: *Pinus ponderosa, Pseudotsuga menziesii, Abies grandis, Pinus contorta,* and *Abies lasiocarpa* (Franklin and Dyrness 1973).

Methods

Mountain goats were captured with drop nets and prepared for transport on Klahhane Ridge in the Olympic Mountains (Johnson and Moorhead 1982, Houston *et al.* 1984). They were transported in individual crates by truck to Lake Chelan and by boat to release sites along the lake.

A total of 44 goats was released. Eighteen females and 11 males were released in 1983 at two sites along the north shore and four along the south shore. Seven females and eight males were released in 1984 at one north shore and one south shore release site (Fig. 1). Group sizes of released goats ranged from 1-10 ($\bar{x}$ = 5.5, n = 8, SE = 2.62).

Guidelines suggested by Hebert *et al.* (1980) were used to select release sites. All release sites had been occupied by goats within the previous 20 years and currently were unoccupied or had goat numbers less than the 1960-70 levels.

At the release sites the goats were collared and/or ear tagged before release. Release sites along each shore were designated by different colored canvas neck collars. Collars were riveted around the necks of adults (goats two years or older). Yearlings and kids were not collared. Males and females were tagged in opposite ears to differentiate sexes. Adults, yearlings, and kids were identified by different colored, numbered, large plastic ear tags. Different ear tag colors were used in 1984 and 1983. This system allowed (if the ear tag number was unreadable) identification of the goat's age class (at release), sex, release site, and year of release. Veterinarians inspected the goats for injury of handling stress prior to release. In 1983, three kids were released simultaneously with the nannies with which they were captured.

Posters distributed in the lake vicinity and local newspaper articles provided project information and requested reports of sightings. In addition to these sightings, Chelan PUD wildlife personnel recorded sightings during winter big game surveys along the lake.

Differences between males and females in distance moved from release sites were analyzed by a standard t-test. Relationships between age and movement distances from release site and

between release group size and goat fidelity to release site were analyzed by linear correlation analysis (Zar 1984).

Results and Discussion

Between their release date and 1 July 1987, 95 sightings (29% from PUD surveys and 71% from the WDW, USFS, and general public) of at least 27 individual transplanted goats were compiled (Table 1). Individual goats identified included 36 sightings of 11 of the 19 released males and 59 sightings of 16 of the 25 released females. Forty-two additional sightings contained insufficient information to establish the identity of individual goats.

Table 1. Sightings of mountain goats released along Lake Chelan, Washington.

Goat[1]	Age at release[2]	Months between release and last observation[3]	No. times observed	Greatest distance from release site (km)	Within 9 km of release site	Remained within Lake Chelan basin[4]	With native goats
Males							
G- 1	1	4	1	35			
G- 6	1	1	2	10		yes	
O- 1	3	24	13	22	yes	yes	yes
B-15	3	13	1	11			
B-20	3	1	1	13		yes	
O- 9	4	1	4	42			
B-16	4	1	2	13		yes	
B- 2	4	13	1	21			
O-14	6	16	3	16		yes	yes
O-11	6	40	5	21			
O-13	6	3	3	14		yes	yes
Totals			36		1	6	3
Means			$\bar{x}$ = 3.3	$\bar{x}$ = 19.8 (SE = 10.2)			
Females							
K- 3	0	<1	1	3	yes	yes	
G- 2	1	37	2	2	yes	yes	yes
G- 5	1	35	4	5	yes	yes	yes
G- 7	1	7	5	11		yes	
O- 2	2	46	2	5	yes	yes	yes
O- 6	2	42	2	3	yes	yes	yes
O-18	3	37	9	27			yes
O-12	4	37	9	38		yes	yes
O- 7	6	25	4	5	yes	yes	yes
O- 8	6	15	9	58			
O-17	6	23	2	14		yes	
O- 4	7	13	1	3	yes	yes	yes
B-21	8	2	1	5	yes	yes	
O-16	A	1	2	13		yes	
B- 5	A	25	3	19			
B-13	A	25	3	11	yes	yes	yes
Totals			59		9	13	9
Means			$\bar{x}$ = 3.7	$\bar{x}$ = 13.9 (SE = 15.4)			

[1]Goats designated by ear tag color (K = black, G = green, O = orange, B = blue) and number.

[2]Age at release (A = adult of unknown age).

[3]Number of months between release and last sighting (rounded to nearest month).

[4]Last sighting indicated that goat was within Lake Chelan drainage.

Males moved 10-42 linear km ($\bar{x}$ = 19.8, n = 11, SE = 10.2) from their release sites. Females moved 2-58 linear km ($\bar{x}$ = 13.9, n = 16, SE = 15.4) from release sites but half of them were never seen more than 3 km from their release sites. Distances moved by males and females were not statistically different ($P > 0.5$). There was no relationship ($r = .11$ for males; $r = .26$ for females) between age and distance that goats traveled (Table 1). Although our release group sizes were relatively small, there was a significant relationship ($r = 0.65$, $P > 0.05$) between release group size and the number of goats which stayed within 9 km of their release sites. Goats released in large groups tended to remain closer to release sites than did goats released in smaller groups.

Six or seven of the eight goats released at Box Canyon (Fig. 1) and five released at nearby Still Creek (Fig. 1) remained in that area and formed the nucleus of a band which now represents the furthest "downlake" goat band. That area was unoccupied by goats at the time of release. This was the only release in which enough goats remained to colonize a release area. A wildfire burned this area in 1978 and natural revegetation has provided good forage conditions. The burn may have enhanced conditions for goats and may be a reason that released goats colonized this area.

Only one of the 11 transplanted males which were resighted along Lake Chelan stayed within 9 km of its release site. This male, however, moved 22 km and then returned to the release site area. Nine of the 16 resighted females along Lake Chelan remained within 9 km of their release sites. One of these nine females was found dead within two months after release and a kid was only seen once, five days after release. The male and five of the females which remained within 9 km of their release sites were from the Box Canyon and Still Creek releases.

Under natural conditions, native mountain goats have relatively small home ranges (Adams *et al.* 1982). Dispersal movements from natal sites by native goats may be caused by males seeking females and females seeking improved nutritional conditions (Stevens 1983). Our study indicates that a large proportion of transplanted goats moved away from release sites and traveled further than normal dispersal movements of native goats.

The longest movement from a release site that we know of by one of the transplanted goats was 58 linear kilometers by a six-year-old female in which she crossed the Entiat and Wenatchee river drainages. An adult male (O-9) was seen 42 linear km from its release site 13 days after release. Seven days later, he was sighted 22 linear km closer to his release site. Sightings of an adult female (O-18) indicate a movement totaling a minimum of 67 linear km away from her release site over three years. She was released at Round Mountain on the north shore in 1983 and was seen there in 1984 with a kid. Later that summer, she and the kid were seen near Agnes Creek above the northwest end of the lake. In 1986, she was seen at Ice Lakes, south of Lake Chelan, with another kid. Another adult female, which had been transplanted with her kid, was seen (11 days after release) swimming from the south to the north shore of Lake Chelan in an area where the lake is about 1.8 km wide. Two weeks later, she was seen again in the same general area, swimming back to the south shore.

Five of the 11 resighted males and three of the 16 resighted females left the Lake Chelan drainage. Four of these eight goats (two from release sites at Pyramid Creek, one from Box Canyon, and one from Round Mountain) were eventually sighted in the Ice Lakes vicinity at the headwaters of the Entiat River. Three goats from the Still Creek release site moved to the west side of the Entiat Valley. One of these three eventually continued on to the Chiwaukum Mountains, west of the Wenatchee River. Another goat moved from the Chelan drainage northeast to the Methow River drainage (18 km from its release site). Two of the resighted goats which left the Chelan drainage were sighted within the drainage during their first year of release but were sighted outside the drainage two and three years after release.

Three of the 11 resighted males were seen with native goats, compared to nine of the 16 resighted females. All of these goats, except one male, were present along Lake Chelan for at least one breeding season. This would have allowed the addition of new genetic strains from the Olympic Mountains to the Lake Chelan population which is considered a transplant benefit.

At least ten kids were produced from transplanted nannies during the three summers following the initial release. Three kids were

produced in 1984, from the 13 nannies released in 1983, and two and five kids in 1985 and 1986, respectively, from transplanted nannies.

At least three transplanted goats have died since release. An adult female was found dead below a cliff 5 km from its release site, two months afters its release. A yearling male and an adult female were shot by goat hunters after moving from the Lake Chelan area into areas open to goat hunting. The male was shot during the fall of its release and the female was shot during the fall of the year following its release.

We believe that the survival rate of transplanted kids was low. One of the three transplanted kids was seen once five days after release. Two of the three nannies which had been transplanted with kids were seen within one and six months of release and neither of them was with a kid. During the winter of 1983-84 goat surveys along the lake, we emphasized examining kids for ear tags, but saw none.

Kids may experience poor survival after capture and transplant because of muscle myopathy (C. Robbins and S. Parrish, Wa. St. Univ., pers. comm.) or separation from their nannies. If other needs for kids exist (i.e., zoos, wildlife research), they might be better utilized than in transplants.

Collaring and ear tagging released goats provided an inexpensive method of monitoring movements and individual behavior. Collars and numbered ear tags were still identifiable four years after goats were released.

The Lake Chelan goat transplant should be considered successful. Goat numbers were increased along the lake. Goats released at Box Canyon colonized that previously unoccupied area. Most released goats which moved from their release areas joined existing bands in other areas within the Lake Chelan drainage. During the summers of 1984-86, a minimum of ten kids were born to nannies transplanted along Lake Chelan.

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Habitat Use of Twenty-five Common Species of Oregon Freshwater Fishes

Abstract

This study had two objectives. The first was to determine the use of the physical habitat by the 25 most common native freshwater fishes of Oregon, and the second was to evaluate the use of a large computer database of museum records in the determination. The database encompasses 2021 collections made by various field workers from 1880 to 1984. Statistically distinct habitat use patterns appear for 17 of the species for temperature, 17 for substrate, 19 for stream width, and 22 for current velocity. Habitat use identified from this statistical evaluation is generally consistent with the subjective evaluations of field ichthyologists, and the study revealed additional information for some species. A large computer database compiled from field notes of many collectors allowed useful generalizations concerning species habitats, even though methods of collecting and recording differed greatly. Such databases also permit greater quantification than is typical of species accounts and more robust habitat descriptions than those gleaned from a small number of site specific studies.

Introduction

The objective of this paper is to examine, through statistical analysis of a large computer database, the use of certain aspects of the physical habitat by common freshwater fish species of Oregon. Evaluations of habitat use of many of these species plus others are provided in several standard reference works (Morrow 1980, Moyle 1976, Scott and Crossman 1973, Simpson and Wallace 1978, Wydoski and Whitney 1979). These habitat descriptions are drawn largely from decades of field experience by professional ichthyologists, from intensive research by students examining particular species in particular drainages (e.g., Finger 1979, Ikusemiju 1967, Mathews 1962), and from laboratory studies of particular species (e.g., Ferguson 1958).

We believe that statistical analyses of extensive historical data on habitats of species and their occurrences provide valuable supplements to published material. Such analyses are generally more defensible than qualitative evaluations of field notes and offer greater geographic and temporal coverage than studies of given sites or drainages.

Methods

We compiled a database of more than 9000 collections of freshwater and euryhaline fishes in Oregon. These data were collected during the past century and obtained from the ichthyological collections of the Department of Fisheries and Wildlife, Oregon State University; the University of Michigan Museum of Zoology (UMMZ); and the California Academy of Sciences (CAS) (Rexstad 1987). Eighty-six percent of the collections were made since 1950.

The field collections from which the database is constructed were made by many persons for many different purposes. There was no standard method of collecting or of assessing environmental conditions, and there were obvious biases for season and locality. In the database, observations of habitat-species relationships ranged from detailed measurements of habitat for each collected individual to broad characterizations of the entire collection site generalized to individual species. Although the database is more useful for studying species distributions and communities (Hughes *et al.* 1987) than for examining habitat use patterns, we believe that the included data on habitat provides useful information for the most common species.

The database contained information on up to 50 variables for each collection, including aspects of geography, associated fauna, and descriptions of physical and biological habitat. These data were checked rigorously before being entered into the database and subsequently scrutinized by automated error-detection software. Variables subjected to analysis and the numbers of collections for which each is recorded are the following: water temperature (1792); substrate composition (2021); stream width (1577) and current velocity (1876).

Because we were concerned with evaluating use of particular habitat variables by particular species, and did not wish to determine the portion of a general environmental gradient along which several species are distributed, we chose chi-square analysis over principal components analysis (PCA). Although PCA is an effective tool for evaluating multivariate gradients (Felly 1984, Matthews 1985, Grossman and Freeman 1987), we considered chi-square more appropriate to our data, in that it allows greater opportunity than PCA to assess the importance of individual variables for particular species. Only four habitat variables in the database represented a sufficient number and quality of collections, precluding the need to distill mathematically a small number of variables from the database. Also, spurious correlations among species and habitat variables that are masked by PCA (Beals 1973) are more clearly revealed by examination of the separate variables in chi-square analysis. Finally, chi-square analysis provides a useful tool for examining habitat use of individual species rather than guilds.

Chi-square was used to determine whether the frequency with which a species occurred under particular conditions differed substantially from the hypothetical population frequency. The distribution of observations over all species for each habitat category served as an expected distribution of habitat. To test for departure from expected distributions, chi-square tests for multinomial data (Ostle and Mensing 1975) were performed for each species and habitat category.

Results and Interpretation

Frequency of Occurrence

The frequency with which species appear in the database reflects their ubiquity, the extent of their distribution in Oregon and collecting effort (Table 1). Most species in Table 1 probably appear in relation to their availability to collectors. The 784 collections of speckled dace, *Rhinichthys osculus,* document its ecological versatility and presence in nearly all drainages in the state. The reticulate sculpin, *Cottus perplexus,* the second most frequently collected species, is ubiquitous in western Oregon, where 62 percent of the collections were made. The rainbow trout, *Salmo*[1] *mykiss,* although somewhat restricted ecologically, is found in nearly all drainages, so its appearance as the third most frequently collected species is not surprising. Two Klamath Basin species (marbled sculpin, *Cottus klamathensis,* and blue chub, *Gila coerulea*) represent an

TABLE 1. The most frequently occurring freshwater fish species in the Oregon database.

Rank	Species	Number of Collections
1	*Rhinichthys osculus*	784
2	*Cottus perplexus*	660
3	*Salmo mykiss*	612
4	*Richardsonius balteatus*	531
5	*Salmo clarki*	416
6	*Cottus rhotheus*	366
7	*Oncorhynchus kisutch*	348
8	*Gila bicolor*	332
9	*Catostomus macrocheilus*	306
10	*Ptychocheilus oregonensis*	286
11	*Oncorhynchus tshawytscha*	251
12	*Lampetra tridentata*	240
13	*Rhinichthys cataractae*	229
14	*Cottus asper*	218
15	*Cottus aleuticus*	192
16	*Cottus gulosus*	163
17	*Cottus beldingi*	149
18	*Acrocheilus alutaceus*	146
19	*Salmo* sp. (redband trout)	143
20	*Cottus klamathensis*	133
21	*Gasterosteus aculeatus*	126
22	*Catostomus columbianus*	125
23	*Gila coerulea*	122
24	*Micropterus salmoides*[1]	121
25	*Ictalurus nebulosus*[1]	101
26	*Cottus confusus*	97
27	*Lampetra richardsoni*[2]	91

[1]Introduced species

[2]Includes *Lampetra pacifica*

[1]Because the generic status of the native trouts of the Pacific drainage is currently under debate, but not yet agreed upon by systematic ichthyologists, we are conservatively using *Salmo* instead of the recently used *Parasalmo,* which appears to be a junior synonym of *Rhabdofario,* or *Oncorhynchus,* to which these trouts may eventually be referred. We accept the priority of *mykiss* over *gairdneri.*

unexpected proportion because of an extended project that resulted in 986 collections (11 percent of the database) from the basin.

Native fishes dominate Table 1. In fact, of the 36 introduced species in Oregon, only six appear among the 40 most-frequently collected. Most of the introduced fishes such as the centrarchids, percids and ictalurids are panfishes or sportfishes that have become established and sometimes dominate in warm, lentic waters. The common carp, *Cyprinus carpio,* is abundant or dominant in some sloughs, lakes and reservoirs. Brown trout, *Salmo trutta,* and brook trout, *Salvelinus fontinalis,* are successful in some spring-fed and high altitude habitats. In a 1984 survey of 99 relatively undisturbed small streams characteristic of the eight Oregon landscape regions, introduced species were found at 19 sites and represented greater than 10 percent of the individuals at 13 sites (R. M. Hughes pers. comm., Whittier *et al.* 1988). In most undisturbed lotic habitats in the state, native fishes are apparently competing well with introduced species.

Temperature

Most collections recorded in the database were made during summer, the primary field season for research; 90 percent of the records were from April through September. August collections accounted for 23 percent of the total temperature records. The expected distribution of species by water temperatures (n = 1792) was as follows: less than 9.9C, 16.2 percent; 10-14.9C, 23.3 percent; 15-19.9C, 37.2 percent; and 20C or greater 23.4 percent. Of the 25 species included in the study, eight showed insignificant ($P > 0.05$) deviations from the observed distribution of water temperature (Tables 2 and 3). The following discussion pertains only to those species showing significant differences from random

TABLE 2. Chi-square values for distribution of the four habitat variables for each species. Asterisks indicate significance level (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$).

Species	Water Temperature	Bottom Type	Stream Width	Current Velocity
Acrocheilus alutaceus	2.7	4.4	63.3***	8.2*
Catostomus columbianus	55.8***	0.7	16.0**	0.7
Catostomus macrocheilus	3.9	1.8	29.5***	9.4**
Cottus aleuticus	12.5**	24.9***	10.3	27.3***
Cottus asper	12.0**	10.7**	12.7*	7.5*
Cottus beldingi	3.0	40.1***	15.6**	18.7***
Cottus confusus	28.6***	18.1***	52.3***	48.8***
Cottus gulosus	43.1***	15.9***	57.6***	17.7***
Cottus klamathensis	7.7	15.9***	160.5***	18.3***
Cottus perplexus	29.9***	0.9	13.0*	3.6
Cottus rhotheus	17.3***	41.1***	21.9***	9.8**
Gasterosteus aculeatus	11.7**	25.1***	8.3	25.1***
Gila bicolor	23.5***	66.3***	0.8	18.9***
Gila coerulea	32.8***	24.8***	98.5***	21.3***
Lampetra richardsoni[1]	103.2***	9.4**	26.5***	7.0**
Lampetra tridentata	15.0***	6.9*	10.0	25.4***
Oncorhynchus kisutch	92.7***	35.0***	14.3*	16.3***
Oncorhynchus tshawytscha	5.8	27.5***	164.3***	70.8***
Ptychocheilus oregonensis	1.4	3.4	20.6***	19.0***
Rhinichthys cataractae	31.3***	1.3	15.9**	27.1***
Rhinichthys osculus	1.8	1.4	4.8	5.6
Richardsonius balteatus	10.4*	6.9*	7.1	8.8*
Salmo clarki	11.0*	0.5	41.1***	7.7*
Salmo mykiss	1.7	6.6*	15.9**	8.3*
Salmo sp. (redband trout)	10.2*	11.3**	78.4***	16.1***

[1]Includes *Lampetra pacifica*

TABLE 3. Percent occurrence of selected Oregon freshwater fishes by water temperature (degrees Centigrade), sorted in order of increasing occurrence in cool water (occurrence in 0-9.9). Asterisks indicate chi-square significance level (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$).

Species	n	Temperature °C			
		0-9.9	10-14.9	15-19.9	20+
G. bicolor ***	94	4.3	12.2	46.8	36.2
R. balteatus *	103	6.8	19.4	40.8	33.0
R. cataractae ***	50	8.0	6.0	60.0	26.0
G. aculeatus **	30	10.0	16.7	53.3	20.0
A. alutaceus	29	10.3	24.1	41.4	24.1
C. macrocheilus	52	11.5	21.2	46.2	21.2
C. columbianus ***	42	11.9	2.5	33.3	52.3
R. osculus	211	11.9	20.9	37.9	26.5
C. klamathensis	15	13.3	13.3	46.7	26.6
S. mykiss	117	13.7	26.5	40.2	19.7
C. beldingi	35	14.3	17.1	42.9	25.7
P. oregonensis	58	17.3	19.0	41.4	22.4
C. confusus ***	27	18.5	44.4	22.2	14.8
C. rhotheus ***	51	19.2	37.3	33.3	9.8
O. tshawytscha	15	20.0	13.3	40.0	26.6
Salmo sp. (redband trout) *	62	20.0	33.9	32.3	13.9
L. tridentata ***	47	21.3	36.2	29.8	12.8
C. asper **	28	21.5	32.1	35.7	10.7
S. clarki *	36	22.2	30.6	36.1	11.1
G. coerulea ***	21	23.8	9.5	23.8	42.9
C. aleuticus **	33	27.3	27.3	30.3	15.2
C. perplexus ***	132	31.1	31.8	30.3	6.8
C. gulosus ***	27	33.3	37.0	22.2	7.4
L. richardsoni[1] ***	35	45.7	40.0	14.3	0.0
O. kisutch ***	36	50.0	22.2	25.0	2.8
Total collections in database	1792	16.2	23.3	37.2	23.4

[1]Includes *L. pacifica*

distributions, as estimated by our hypothetical distribution calculated from the observations of all species. The western brook lamprey, *Lampetra richardsoni* (includes *L. pacifica*), shows the narrowest range; more than 85 percent of its collections are nearly equally divided between the 5-9.9C and 10-14.9C categories. That distribution probably results from a preponderance of collections (68 percent) during its spawning season (April and May).

The distribution of several species is skewed toward cool water. Fifty percent of the collections of coho salmon, *Oncorhynchus kisutch,* are at temperatures between 0 and 9.9C; 90 percent of the collections of *Cottus perplexus* and Aleutian sculpin, *C. aleuticus,* are nearly equally subdivided among the three categories between 0 and 19.9C. The temperature distributions of redband trout, *Salmo* sp., and cutthroat trout, *S. clarki,* are about 20 percent in 5-9.9C and 30 percent to 36 percent in each of the next two higher categories. Pacific lamprey, *Lampetra tridentata,* and prickly sculpin, *C. asper,* also are found in cool water.

The 10-14.9C interval is typical for shorthead sculpin, *Cottus confusus,* torrent sculpin, *C. rhotheus,* and riffle sculpin, *C. gulosus* (44, 37 and 37 percent respectively), but distribution around this interval differs. More than 33 percent of the *C. rhotheus* collections are in the 15-19.9C interval and over 33 percent of *C. gulosus* collections are in the 0-9.9C range. *C. confusus* is taken about 20 percent of the time in each of those two categories. There are a few collections of *C. gulosus* and *C. confusus* in waters warmer than 25C.

Some species tend to be found in warmer water than these cottids. For example, 60 percent of the longnose dace, *Rhinichthys cataractae,* collections are from 15-19.9C water and 26 percent from temperatures greater than 20C. The threespine stickleback, *Gasterosteus aculeatus,* is found about 17 percent of the time in 10-14.9C, about 53 percent in 15-19.9C and 20 percent in water warmer than 20C. The redside shiner, *Richardsonius balteatus,* occurs in waters warmer than 14.9C about 74 percent of the time and in waters cooler than 10C about 7 percent of the time. About 47 percent of the collections of tui chub, *Gila bicolor,* are from the 15-19.9C interval, and about 36 percent from the 20+ interval. *G. coerulea* appears in water warmer than 20C in 43 percent of the collections. The bridgelip sucker, *Catostomus columbianus,* is significantly over-represented in warm water. It is taken 85 percent of the time in water warmer than 15C; more than 52 percent of the collections are from water temperatures greater than 20C (actually, nearly 7 percent from water > 25C).

Bottom type

Data for bottom type (n = 2021) were interpreted and assigned to the following categories (number in parentheses indicates percentage occurrence in the database over all species): "rubble" (24.0%), which included bedrock, boulders and rubble; "pebble" (57.2%), large to small gravel; and "sand" (18.8%), coarse sand to silt. More refined categories are precluded by the qualitative nature of the data and the differing terminologies used by collectors.

Seventeen species show statistically distinct patterns of substrate use (Tables 2 and 4). *Cottus* species, except for *C. asper* and *C. perplexus*

TABLE 4. Percent occurrence of selected Oregon freshwater fishes by bottom type, sorted in order of increasing occurrence over rubble substrate. Asterisks indicate chi-square significance level (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.005$).

		Bottom Type		
Species	n	Rubble	Pebble	Sand
C. rhotheus ***	45	6.7	88.9	4.4
G. bicolor ***	111	11.7	37.8	50.5
L. richardsoni[1] **	34	11.8	70.6	17.6
G. aculeatus ***	29	13.8	48.3	37.9
P. oregonensis	60	18.3	56.7	25.0
L. tridentata *	53	18.9	69.8	11.3
R. balteatus *	131	19.9	51.2	29.0
C. asper ***	38	21.1	47.4	31.6
C. macrocheilus	71	21.1	54.9	23.9
C. columbianus	49	22.4	61.2	16.3
C. confusus ***	31	22.6	74.2	3.2
C. aleuticus ***	33	24.2	75.8	0.0
C. perplexus	152	24.3	60.5	15.1
R. cataractae	56	25.0	60.7	14.3
S. mykiss *	135	25.2	65.9	8.9
S. clarki	43	25.6	58.1	16.3
R. osculus	238	26.1	59.7	14.3
C. gulosus ***	31	29.0	67.7	3.2
Salmo sp. (redband trout)***	65	29.8	66.2	6.2
A. alutaceus	32	31.3	56.3	12.5
G. coerulea ***	27	33.3	33.3	33.3
C. klamathensis ***	20	40.0	40.0	20.0
O. tshawytscha ***	18	44.4	50.0	5.6
C. beldingi ***	43	46.5	53.5	0.0
O. kisutch ***	63	49.2	36.5	14.3
Total collections in database	2021	24.0	57.2	18.8

[1]Includes *L. pacifica*

usually are found over coarse substrates; *C. asper* is found frequently on sand and *C. perplexus* appears not to discriminate. Pacific salmon, *Oncorhynchus* spp., usually are collected over coarse substrates as is the redband trout and, to a lesser extent, *Salmo mykiss. Lampetra richardsoni* and *L. tridentata* are taken about 70 percent over pebble substrate. *Gasterosteus aculeatus* is collected over fine bottom materials in 38 percent, and *Gila bicolor* in 50 percent of the collections. *Richardsonius balteatus* also tends to be found over fine substrate. *G. coerulea,* which feeds in the water column, appears not to discriminate among the three bottom types. Eight species show insignificant ($P > 0.05$) deviations from the observed distribution of bottom type.

Stream Width

Because stream widths reported in the collections were usually estimates, we categorized the data into broad 10m increments. We felt these categories would offer meaningful estimates of stream sizes for the species examined. The expected distributions (over all species, n = 1577) are 0-9.9 m, 61.1 percent; 10-19.9m, 20 percent; greater than 20m, 18.7 percent (Table 5). Distributions of *Catostomus columbianus; Cottus aleuticus;* Paiute sculpin, *C. beldingi; Gasterosteus aculeatus; Gila bicolor; Rhinichthys cataractae; R. osculus* and *Richardsonius balteatus* are not significantly different from the expected ($P > 0.05$, Tables 2 and 5).

TABLE 5. Percent occurrence of selected Oregon freshwater fishes by stream width (meters), sorted in order of increasing occurrence in streams < 10m wide. Asterisks indicate chi-square significance level (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.005$).

		Width (m)		
Species	n	0-9.9	10-19.9	20+
C. klamathensis ***	16	18.8	18.9	62.6
G. coerulea ***	19	36.8	15.9	47.4
C. confusus ***	29	37.9	37.9	24.1
C. macrocheilus ***	52	38.5	34.6	26.9
A. alutaceus ***	28	39.3	18.0	42.9
P. oregonensis *	45	46.7	28.9	24.5
C. rhotheus ***	51	47.0	33.3	17.7
C. beldingi	33	48.6	24.3	18.2
R. cataractae	50	50.0	28.0	22.0
O. tshawytscha ***	10	50.0	40.0	10.0
L. tridentata *	24	50.0	29.1	20.9
O. kisutch *	52	51.9	30.8	17.3
R. balteatus	88	53.4	21.6	25.0
C. asper *	31	54.8	16.2	29.0
C. columbianus	38	57.9	21.0	21.0
G. aculeatus	28	58.7	17.8	21.4
G. bicolor	73	63.0	19.2	17.8
C. aleuticus	30	63.3	16.7	20.0
R. osculus	191	68.6	17.3	14.1
C. gulosus *	32	71.9	18.8	9.4
S. mykiss **	119	74.8	17.8	7.5
C. perplexus ***	121	76.9	15.7	7.4
L. richardsoni[1] ***	27	85.2	11.1	3.7
S. clarki ***	36	86.1	11.1	2.8
Salmo sp. (redband trout) ***	60	96.7	3.4	0.0
Total collections in database	1577	61.1	20.2	18.7

[1]Includes *L. pacifica*

Except for redband trout, which occur in isolated desert mountain streams, all species are found across the entire range of stream widths. The redband trout is taken almost exclusively in streams less than 10m wide. Also, *Cottus gulosus* is found 72 percent of the time in streams less than 10m wide and *Salmo mykiss, C. perplexus, Lampetra richardsoni,* and *S. clarki* are collected in streams less than 10m wide 75, 78, 85 and 86 percent of the time, respectively.

Some species are significantly over-represented in large water bodies. Collections of chiselmouth, *Acrocheilus alutaceus, Cottus klamathensis,* and *Gila coerulea* deviate from the expected distribution in that more than 40 percent of the collections come from water bodies wider than 20 m. Northern squawfish, *Ptychocheilus oregonensis, Cottus asper* and largescale sucker, *Catostomus macrocheilus* also are significantly over-represented in larger streams. *Cottus confusus; C. rhotheus;* chinook salmon, *Oncorhynchus tshawytscha; O. kisutch* and *Lampetra tridentata* were collected significantly more often from streams in the middle-width category.

Current velocity

Field collectors usually make subjective estimates of current velocity; only occasionally do they measure it. Because most records are based on subjective estimates, we express the data as "slow," "moderate," or "swift," with the three categories corresponding to 0-0.4 meters per second (mps), 0.5-0.9 mps and over 0.9 mps, respectively. Estimates of actual velocity are derived from measurements discussed by Bond (1963). Estimates of velocity reported in the database (n = 1876) are distributed evenly: 30.7 percent slow, 32.9 percent moderate and 36.4 percent swift (Tables 2 and 6). Collections of *Catostomus columbianus, Cottus perplexus* and *Rhinichthys osculus* do not differ significantly from these percentages.

TABLE 6. Percent occurrence of selected Oregon freshwater fishes by current velocity, sorted in order of increasing occurrence in swift water. Asterisks indicate chi-square significance level (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.005$).

Species	n	Velocity		
		Swift	Moderate	Slow
*G. coerulea****	22	18.2	31.8	50.0
G. aculeatus ***	28	19.9	28.6	53.6
G. bicolor ***	85	20.0	30.6	49.4
S. clarki *	42	23.8	40.5	23.8
C. asper *	36	25.0	33.3	41.7
C. macrocheilus **	70	25.7	30.0	44.3
P. oregonensis ***	61	26.6	23.0	50.8
R. balteatus *	127	26.8	29.1	44.1
A. alutaceus *	32	28.1	28.1	43.8
C. klamathensis ***	20	30.0	20.0	50.0
R. osculus	228	32.9	46.0	31.3
Salmo sp. (redband trout) ***	62	33.3	50.0	16.1
C. gulosus ***	28	35.7	50.0	14.3
L. richardsoni[1] *	30	36.7	43.3	20.0
C. perplexus	143	38.5	39.2	22.4
C. columbianus	48	39.6	33.3	27.1
C. rhotheus **	43	44.2	39.5	16.2
S. mykiss **	126	44.7	38.9	17.9
C. beldingi ***	36	50.0	38.9	11.1
O. kisutch ***	57	54.4	17.5	28.1
L. tridentata ***	47	57.5	31.9	10.6
C. aleuticus ***	31	58.1	32.3	9.7
R. cataractae ***	56	58.9	30.4	10.7
C. confusus ***	31	61.3	38.7	0.0
O. tshawytscha ***	15	73.3	0.0	26.7
Total collections in database	1876	36.4	32.9	30.7

[1]Includes *L. pacifica*

Some species appear to inhabit slow water. More than 53% of the collections of *Gasterosteus aculeatus* are from slow water, and collections of *Cottus klamathensis, Ptychocheilus oregonensis* and *Gila coerulea* are 50 percent from slow current. Species collected 40 percent to 50 percent from slow current are *G. bicolor, Catostomus macrocheilus, Richardsonius balteatus, Acrocheilus alutaceus,* and *Cottus asper.*

Species that tend significantly toward moderate current are *Cottus gulosus* and *Salmo* sp., both taken 50 percent of the time in moderate and less than 40 percent in fast water. *S. clarki* also occurs in moderate current to a significant degree, with occurrence in swift and slow water 23 percent of the time. Three species, *C. rhotheus, Lampetra richardsoni* and *S. mykiss,* show collections about 40 percent in moderate current and 44 percent in fast. *Cottus beldingi, C. aleuticus, L. tridentata* and *Rhinichthys cataractae* are similar; only 10-11 percent of the collections are in slow water with 50 to 60 percent in swift water. *Oncorhynchus kisutch* collections are bimodally distributed: 28 percent in slow water, 18 percent in moderate water and 56 percent in swift water. This may be explained by the occurrence of juveniles in the pools or pocket water of fast streams. There is a similarity to this in the distribution of the 15 collections of *O. tshawytscha,* also mainly juveniles. There are no collections recorded from slow water for *C. confusus,* which is taken 61 percent of the time in fast water.

Discussion

Native species outnumber introduced species in most of the largely natural Oregon water bodies sampled. These findings support the conclusions of Leidy and Fiedler (1985), Minckley (1973), and Moyle and Nichols (1973). Their work showed that introduced species tend to disperse and dominate in highly disturbed habitats. However, a much more quantitative assessment of numbers and biomasses of species is needed before any conclusive statement is possible about the relative success of native and introduced fish in Oregon.

Results of this analysis appear consistent with previous descriptions of several of the species considered (Li *et al.* 1987, Moyle 1976, Wydoski and Whitney 1979). For many other species, additional knowledge is provided because so little was published previously. This approach demonstrates how certain species, such as *Rhinichthys osculus,* can be considered as habitat "generalists." Such species show no significantly distinct patterns for any of the four variables studied; they occur in a wide variety of habitat conditions. *Catostomus columbianus* and *Cottus perplexus* can be considered current/substrate generalists. *Richardsonius balteatus* appears to be a thermal/stream-size generalist. Other species, such as *Cottus confusus* and *C. gulosus,* have very specific habitat requirements.

Two recent papers propose models for species distribution and abundance. Our data, based on common species, could not be used to evaluate Hanski's (1982) satellite species or Matthews' (1985) rare-habitat specialists and rare-habitat generalists hypotheses. Data for the common species, however, reveal common-habitat specialists (*Oncorhynchus kisutch*) and common-habitat generalists (*Rhinichthys osculus*) as defined by Matthews. *R. osculus* cannot be considered a core species as defined by Hanski. Core species are regionally common and locally abundant, but well-separated in niche space, which *R. osculus* is not.

The chi-square analysis is useful for analyzing habitats of individual species. Although we analyzed each habitat variable separately, we did not assume they were independent. The groupings of most species in Tables 3-6 reveal the expected habitat guilds (warm water, fine substrate, large streams, low velocity versus cool water, coarse substrate, small streams, high velocity, versus intermediate conditions). Some species (e.g., *Gila bicolor* and *Cottus confusus*) do not fit these guilds. *G. bicolor* is significantly over-represented in waters of warmer temperature, lower velocity, and sandy substrate, but does not differ significantly from the expected stream-width frequency. *C. confusus* is significantly over-represented in waters of moderate temperature, pebble substrate and moderate width, but in swift, rather than moderate, velocity waters. Such habitat use patterns would not have been revealed by PCA.

The database provided a general, statewide overview of statistically distinct patterns of fish habitat use. This type of analysis provides meaningful insights about the general habitat-use patterns of species. Intensive studies of a species' habitat in particular drainages may not be applicable throughout the species' range. This is

because a species may occupy a wider range of habitats than is evident from a study in a particular drainage. It is useful to compare regional habitat use patterns just as taxonomists and systematists compare morphometric and meristic characteristics of fish collected across large geographic regions. Incipient speciation may be indicated where a regional analysis demonstrates clear differences between distinct populations of a species.

A computer system for storing and retrieving biological field data for the entire nation has been developed by the U.S. Environmental Protection Agency (BIOS, Lamborne 1986). BIOS allows scientists to analyze rapidly species habitat use patterns on a nationwide basis. Detailed analyses of fish habitat data on this scale await data storage. Such analyses could improve the form of habitat suitability curves used in Habitat Evaluation Procedures (HEP, U.S. Fish and Wildlife Service 1980) and could encourage greater consistency among state fish books. Ornithologists have been using nationwide Christmas and breeding bird counts for several years to assess such habitat use patterns. This paper is an example of the habitat generalizations possible using large databases of fish collections.

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Surface Morphology of Basidiospores from Decay Fungi That Are Common in Pacific Northwest Forests

Abstract

Hymenomycetes are a worldwide group of fungi, several species of which cause serious decay in the roots and stems of conifers. New infections by these fungi are often established by airborne spores; however, species identification based solely on these spores has proven difficult, especially when only light microscopy is used. We thus employed scanning electron microscopy (SEM) to characterize spore types. Basidiospores and conidia of *Heterobasidion annosum* were compared with basidiospores from nine other species of wood decay fungi: *Fomitopsis cajanderi, F. pinicola, Phellinus robustus, Ganoderma applanatum, G. oregonense, Phaeolus schweinitzii, Trichaptum abietinum, Bjerkandera adusta,* and *Trametes versicolor.* Light microscopy demonstrated differences in spore size but did not consistently resolve variations in shape and ectosporal structure. SEM provided a more reliable means for distinguishing among basidiospores and identifying species. Structure beyond the resolution of light microscopy was resolved with the SEM, which should improve the accuracy of taxonomic descriptions. Comparisons among all spore types demonstrated distinct differences that aid in identification of spores collected in airborne samples—including types of inocula for *H. annosum,* the cause of a major root disease in Pacific Northwest forests. The latter information should help to clarify the role of asexual conidia in development of annosus root disease.

Introduction

Hymenomycetes are common decay organisms in forests worldwide. One of these fungi, *Heterobasidion annosum* (Fr.) Bref. [*Fomes annosus* (Fr.) Karst.] causes serious root and butt rot in many species of conifers (Bega 1963, Gilbertson and Ryvarden 1986), including several in the Pacific Northwest (Hadfield *et al.* 1986).

Previous studies on establishment of new infections by *H. annosum* have dealt with airborne inocula in a collective sense because this fungus produces conidia and basidiospores that appear similar when viewed with light microscopy (LM). Using techniques of scanning electron microscopy (SEM), however, Shaw and Florance (1979) were able to distinguish between these conidia and basidiospores. This technique allows for the identification of specific spore types in samples of airborne inocula, an area of research for which the critical need for study has been noted for some time (Bega 1963, Kallio 1970, Lowe 1957, Morris and Knox 1962, Roll-Hansen 1940, Stambaugh *et al.* 1962), but not adequately addressed (Florance *et al.* 1981, Leslie 1983, Shaw and Florance 1979).

Before spores in samples of airborne inocula can be accurately identified, however, the characteristics of other spores that might appear in the samples require elucidation. The objective of this study was to characterize the features of ectosporial wall morphology visible with LM and SEM for decay fungi common to forests in the Pacific Northwest where *H. annosum* causes disease (Russell and others 1973). The spore features were then compared to those of *H. annosum* (Roll-Hansen 1980, Shaw and Florance 1979).

Materials and Methods

Fomitopsis pinicola (Swartz: Fr.) Karst. [*Fomes pinicola* (Swartz ex Fries) Cooke], *Phellinus robustus* (Karst.) Bourd. & Galz. [*Fomes robustus* Karst.], *Fomitopsis cajanderi* Karst. [*Fomes cajanderi* Karst.], *Ganoderma oregonense* (Murr.) Kauffman, *G. applanatum* (Pers. ex Wallr.) Pat., *Phaeolus schweinitzii* Fries, *Trichaptum abietinum* (Dicks.: Fr.) Ryv. [*Polyporus abietinus* Dicks ex Fries], *Bjerkeandera adusta* (Willd.: Fr.) Karst. [*Polyporus adustus* Willd. ex Fries], and *Trametes versicolor* (L.: Fr.) Pilat. [*Polyporus versicolor* L. ex Fries] are common decay fungi in forests of the Pacific Northwest (Gilbertson and Ryvarden 1986, 1987, Partridge and Miller 1974). Fresh basidiocarps of these fungi were collected from forest sites in the Coast and Cascade

Ranges of Oregon in autumn. Samples for LM were macerated on a glass slide and mounted in a Lactophenol medium for viewing with a Nikon Microflex Model EFM Microscope. Spores were examined with an oil immersion objective (NA = 0.65) and photographed with Kodak Technical Pan 2415 (ASA = 125) film.

Spores for SEM were obtained from the same basidiocarps by removing pieces of the hymenophore about 0.5 cm^2 and fixing them with 4 percent glutaraldehyde, 6 percent paraformaldehyde, and 1 percent acrolein in a 0.2 molar cacodylate buffer. Subsequently, samples were rinsed twice in fresh buffer, transferred to Flor-thru tissue carrier vials (American Optical Co.) and dehydrated in an ascending series of four ethanol-distilled water solutions (25, 50, 75, and 100 percent), followed by an ascending series of four ethanol-trichlorotrifluoro-ethane (TF) solutions (25, 50, 75, and 100 percent TF). Spores and tissue remained in each solution, including fixative, for 10 minutes. After treatment in 100 percent TF, samples were dried by the critical point method (Cohen *et al.* 1968), mounted on SEM studs, coated with a platinum-paladium alloy, and viewed with an AMR 1200 Scanning Electron Microscope. Data were recorded on Polaroid Type PN55 (4 by 5 in, 10.1 by 12.7 cm) land film.

Results

Basidiospore Structure

With LM, basidiospores of *F. cajanderi* appeared hyaline, smooth, elongate-cylindrical, sometimes allantoid, and measured 2-2.5 by 5-7 μm (Fig. 1A). The SEM clearly showed an apiculus (= hilar appendix) not resolvable with LM (Fig. 2A) that protrudes 200 nanometers (nm) from the spore surface and is 500 nm in diameter. In scanning eletron micrographs, spores appear smooth and primarily allantoid (Fig. 2A); however, when they are rotated away from the curve, they appear straight (Fig. 2A).

With LM, basidiospores of *F. pinicola* appared ovoid to subglobose, hyaline, smooth, and measured 5-7 by 3-4 μm (Fig. 1B). Spores appeared similar to those seen with SEM, including the smooth surface (Fig. 2B); however, the eccentrically located and abruptly protruding apiculus is more distinct with SEM. The apiculus protrudes 315 nm from the spore surface and is 420 nm in diameter.

With LM, basidiospores of *Phellinus robustus* appeared globose, smooth, hyaline, apiculated, and measured 5-6 μm in diameter (Fig. 1C). With SEM, smooth biconcave or triconcave spores were revealed (Fig. 2C). The apiculus protrudes 400-500 nm from the spore surface and is about 200 nm in diameter. Concavities viewed with the SEM cannot be distinguished with the LM, although there was some indication of their presence.

With LM, spores of *G. applanatum* appeared ovoid, smooth to slightly echinulated, brown, and measured 6-9 by 5-6 μm with LM (Fig. 1D). Some spores also appeared truncated. With SEM, a foveate ectosporium was visible on each spore (Fig. 2D). A concavity was also apparent at the distal end on spores separated from the sterigmata (Fig. 2D).

With LM, basidiospores of *G. oregonense* appeared ovoid, truncated, possibly echinulated, brown, and had a thick outer wall (Fig. 1E). The spores are relatively large compared with the others and measured 10-14 by 7.5-9 μm. With SEM, the ectosporium appeared somewhat foveate—similar to that of *G. applanatum;* however, the depressions were not as deep. A feature resolved by SEM was small, irregularly sized pits or pores in the ectosporium (Fig. 2E). The largest pit measured 416 by 332 nm, just slightly above the resolving power of LM; however, most pits are smaller and would not be resolved with LM.

With LM, Basidiospores of *Phaeolus schweinitzii* appeared ellipsoid to ovoid, smooth, hyaline, apiculate, and measured 5.5-8 by 4-5 μm with LM (Fig. 3A). With SEM, these spores appear similar; however, more accurate measurements of the apiculus can be made with SEM (Fig. 4A). The apiculus protrudes about 480 nm from the spore surface and is about 720 nm in diameter.

Spores of *Trichaptum abietinum* appeared cylindric to allantoid, hyaline, smooth, and measured 4-6 by 1.5-2.5 μm with LM (Figure 3B). With SEM, a very wrinkled ectosporium was visible (Fig. 4B) that was not resolvable with LM (Fig. 3B).

With LM, basidiospores of *B. adusta* appeared oblong to oblong-ellipsoid, smooth, hyaline, and measured 4-5 by 2-3 μm (Fig. 3C). These spores appear almost identical to those of

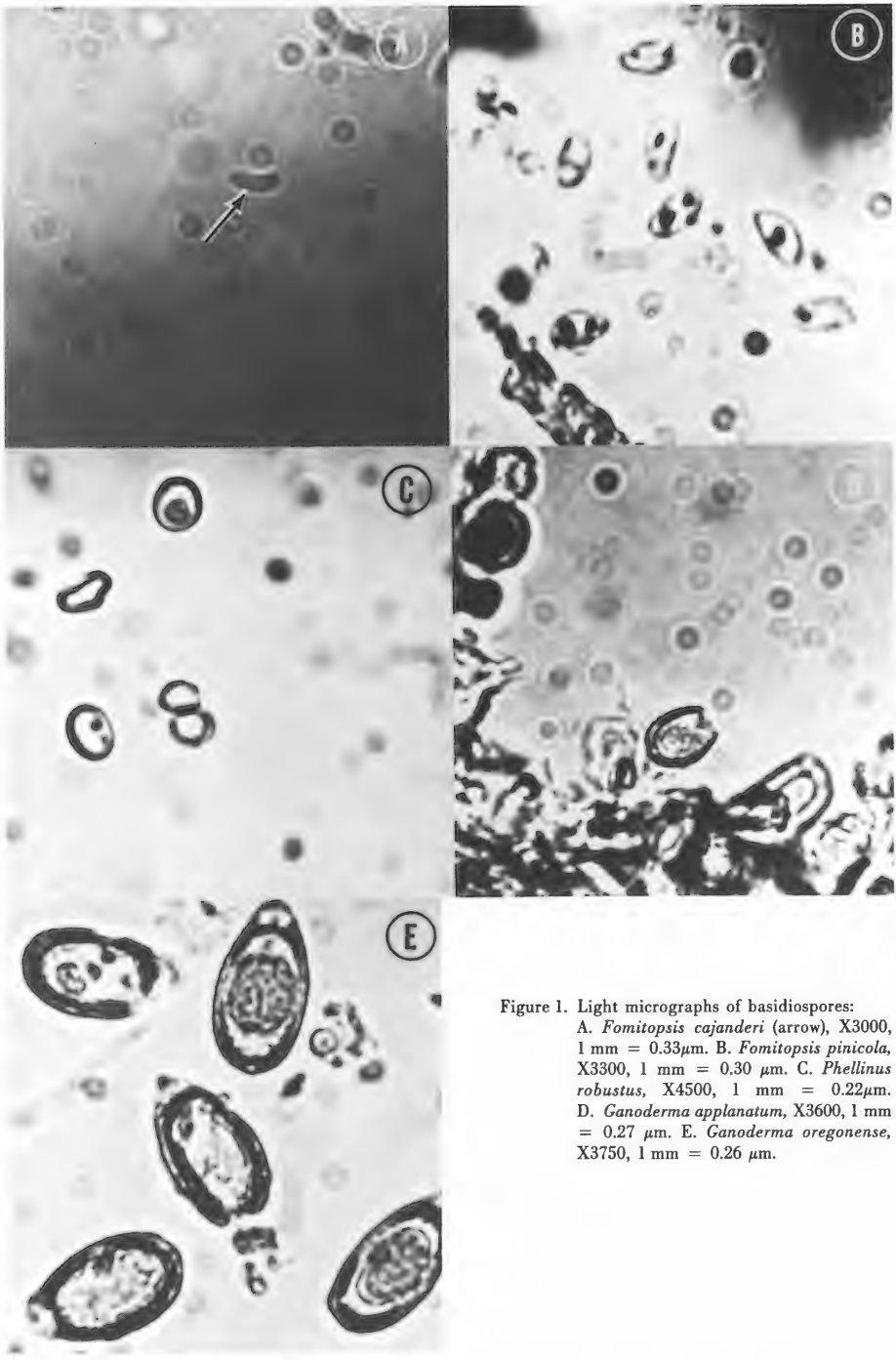

Figure 1. Light micrographs of basidiospores: A. *Fomitopsis cajanderi* (arrow), X3000, 1 mm = 0.33μm. B. *Fomitopsis pinicola,* X3300, 1 mm = 0.30 μm. C. *Phellinus robustus,* X4500, 1 mm = 0.22μm. D. *Ganoderma applanatum,* X3600, 1 mm = 0.27 μm. E. *Ganoderma oregonense,* X3750, 1 mm = 0.26 μm.

Figure 2. Scanning electron micrographs of basidiospores:
A. *Fomitopsis cajanderi;* note apiculus (Ap), allantoid and straight spore morphologies, X13380, 1 mm = 0.07 μm. B. *Fomotipsis pinicola;* note smooth surface and apiculus, X10555, 1 mm = 0.09 μm. C. *Phellinus robustus;* note concavities and apiculi, X7344, 1 mm = 0.14 μm. D. *Ganoderma applanatum;* note foveate surface and concavity at distal end, X7375, 1 mm = 0.13 μm. E. *Ganoderma oregonense;* note pits (Pi) in ectosporial wall, X6800, 1 mm = 0.15 μm.

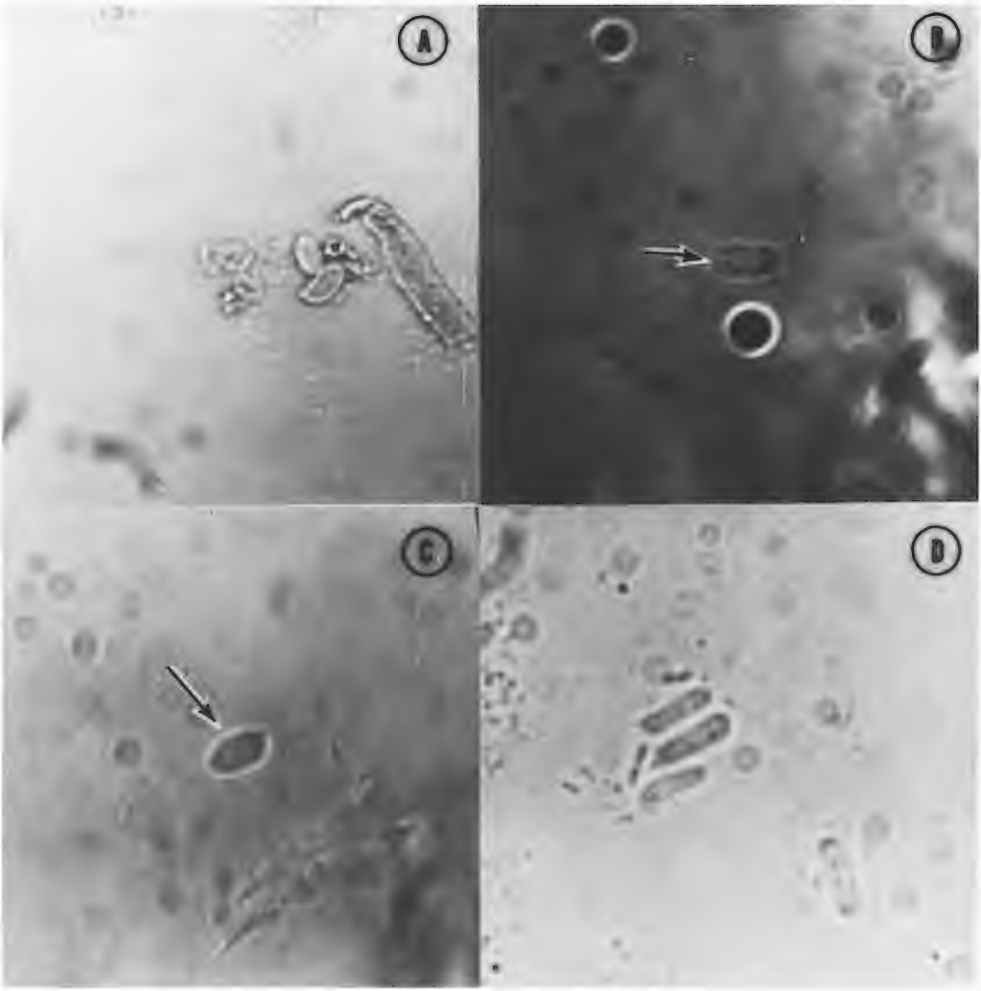

Figure 3. Light micrographs of basidiospores:
A. *Phaeolus schweinitzii,* X4000, 1 mm = 0.25 μm. B. *Trichaptum abietinum* (arrow), X5000, 1 mm = 0.20 μm. C. *Bjerkandera adusts* (arrow), X5000, 1 mm = 0.20 μm. D. *Trametes versicolor,* X3000, 1 mm = 0.33 μm.

T. abietinum. In contrast to LM, SEM revealed a very wrinkled ectosporium, again similar to that of *T. abietinum* (Fig. 4C).

Basidiospores of *Trametes versicolor* appeared cylindric, oblong or slightly allantoid, smooth, hyaline, and measured 4-6 by 1.5-2 μm with LM (Fig. 3D). Except for a wrinkled ectosporial surface visible with SEM (Fig. 4D), all other spore features correlated with those observed by LM.

Comparisons with Spores of *Heterobasidion annosum*

Basidiospores of *H. annosum* show distinct differences from spores of each of these nine species (compare Fig. 5B with Figs. 2 and 4). Echinulations on basidiospores of *H. annosum* are a surface feature that makes this species unique among the 10 species (Fig. 5B). Contrarily, conidia of *H. annosum* are not as distinctive as

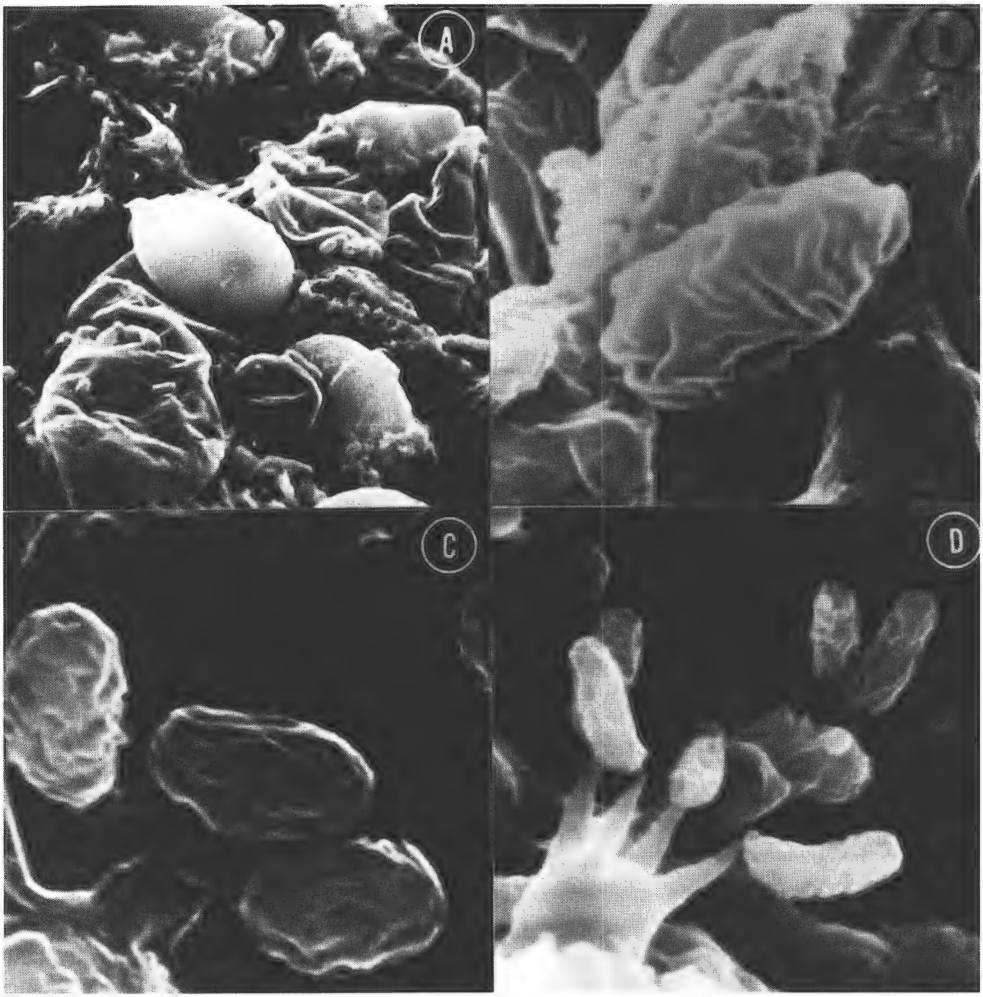

Figure 4. Scanning electron micrographs of basidiospores:
A. *Phaeolus schweinitzii;* note apiculus, X3928, 1 mm = 0.25 μm. B. *Trichaptum abietinum,* X19412, 1 mm = 0.05 μm. C. *Bjerkandera adusta,* X10607, 1 mm = 0.09 μm. D. *Trametes versicolor,* X9945, 1 mm = 0.10 μm. Note wrinkled surface on spores in B, C, and D.

basidiospores (compare Fig. 5A with Figs. 2 and 4). Their smooth ectosporium is similar to basidiospores of *F. pinicola, Phellinus robustus,* and *Phaeolus schweinitzii.* Apicular structure and position are, however, different enough to allow for accurate separation of the species.

Certainly, when compared with basidiospores of *F. cajanderi, G. oregonense, G. applanatum,* and *Trichaptum abientinum, B. adusta,* and *Trametes versicolor,* the conidia of *H. annosum* are distinct.

Discussion

Ectosporial ultrastructure and morphology were characterized and compared for nine species of decay fungi. Distinct differences were observed among most species, and in most, features were

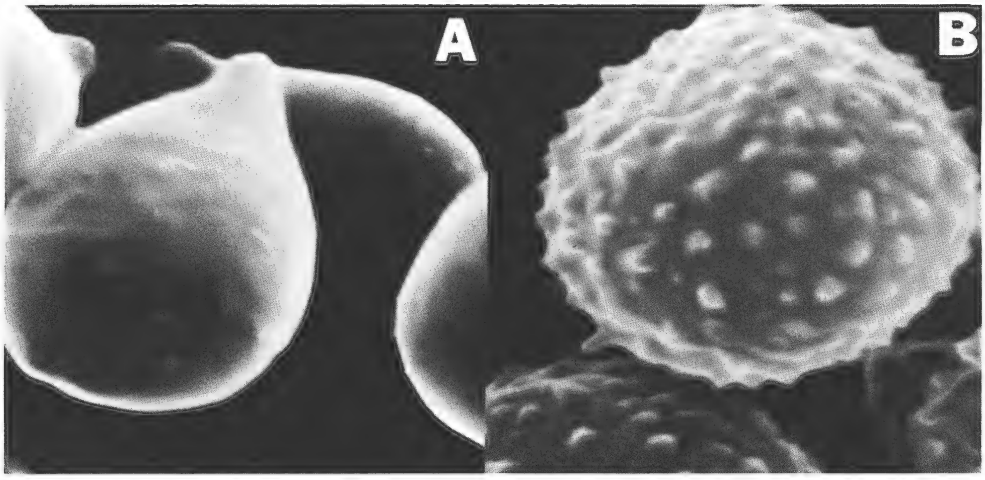

Figure 5. Scanning electron micrographs of:
A. *Heterobasidion annosum* conidia, X15683, 1 mm = 0.06 μm. B. Basidiospores, X20255, 1 mm = 0.05 μm. Compare all scanning electron micrographs of basidiospores in Figures 2 and 4 with those in Figure 5.

resolved with SEM that could not be resolved with LM.

Spores of *Phellinus robustus* are reported to be globose or subglobose (Lowe 1957, Overholts 1977). SEM reveals that these spores have deep depressions and are biconcave or triconcave (Fig. 2C). Variation in the number of depressions likely contributed to reported differences in spore shape reported elsewhere (Lowe 1957, Overholts 1977). Gilbertson and Ryvarden (1987) indicate that the *P. robustus* complex is probably the most difficult taxonomic problem in the genus. By their new descriptions, our specimens may be *P. hartigii* (Allesch. & Schnabl) Bond. because this is the most common species in coniferous forests of the Pacific Northwest, and *P. robustus sensu stricto* causes primarily a heartwood decay of living hardwoods.

Overholts (1977) reported spore surfaces of *G. oregonense* to be "apparently echinulate." SEM shows that the echinulated appearance is caused by numerous pits in the ectosporial wall (Fig. 2E) and is similar to that of many of the British species of *Ganoderma* (Pegler and Young 1973). The pits cause constructive and destructive interference of light and thus contribute to the surface patterns visible with LM (Fig. 1E). Gilbertson and Ryvarden (1986) suggest that these pits result from points of outer wall connection with interwall pillars.

Spores of *G. applanatum* are reported to be smooth when observed by LM (Overholts 1977). Our Figures, and those in Nilsson (1983) and Pegler and Young (1973), indicate a foveate surface (Fig. 2D). In addition, spores released from sterigmata are concave at the distal end, a feature that likely contributes to the descriptions of truncate spores (Gilbertson and Ryvarden 1986, Overholts 1977).

A feature common to *Trichaptum abietinum, B. adusta,* and *Trametes versicolor* is the wrinkled ectosporium (Fig. 4B, C, D). Initially, we thought the wrinkling was caused by preparatory techniques; however, several techniques were used (air drying, fixing for different time periods, using different fixatives, omitting critical point drying) and results were identical. Also, samples of other species were not similarly affected by these preparatory techniques, nor was the basidium of *T. versicolor* wrinkled or distorted (Fig. 4D). Therefore, we conclude that spores of these species will always appear wrinkled when observed with SEM. The wrinkles are either not resolvable with LM (Fig. 3B, C, D), which would explain the lack of earlier observation (Gilbertson 1974, Gilbertson and Ryvarden 1986, 1987), or they are an artifact of our collection procedures or preparatory techniques for SEM. Possibly these fungi have an extremely delicate endosporial, episporial, and perisporial

structure that is altered regardless of preparatory procedures. A study of the genus using thin sectioning and transmission electron microscopy could answer this question; however, such a study is beyond the scope of this project.

Confusion about the distinction between spores of *F. cajanderi* and *Phellinus robustus* exists in the literature (Lowe 1957, Overholts 1977). Lowe (1957) states that *P. robustus* "is very similar to *F. cajanderi* except for the straight thicker spores." In contrast, Overholts (1977) states, "the significant difference between the two species lies in the size and shape of the spores." Emphasis is placed on the allantoid shape. Our results show that even though the spores of *F. cajanderi* are allantoid, this shape is not a reliable feature for separation. Figure 2A shows one spore where the curved morphology is obvious, whereas the other spore appears straight. The condition varies, depending on spore position, because spores viewed with LM are in liquid medium and thus could be variously oriented. This situation likely contributed to differences in earlier descriptions. Gilbertson and Ryvarden (1986, 1987) do not mention problems with distinguishing between spores of these two fungi; however, they do note that *F. cajanderi* has curved spores, whereas the closely related *F. rosea* (Alb. et Schw.: Fr.) Karst. has straight spores.

All nine spore types were compared to an earlier characterization of *H. annosum* spores (Roll-Hansen 1940, 1980, Shaw and Florence 1979) to evaluate the possibility of detecting the presence of this species by identifying its spores in a mixed sample of airborne inocula. Results demonstrate differences in ectosporial structure or morphology among the nine species examined and basidiospores of *H. annosum* (compare Figs. 2 and 4 with Fig. 5). The smooth ectosporium on conidia of *H. annosum* is similar to that on basidiospores of *F. pinicola, Phellinus robustus, F. cajanderi,* and *Phaeolus schweinitzii.* We believe, however, that there are enough differences in overall morphology, ectosporial structure, and apicular attachment to accurately identify these conidia in samples of airborne inocula. Since conidia may be an important source of inoculum for *H. annosum* in West Coast forests (Hunt *et al.* 1976), knowledge of their abundance in airborne inocula could be important to forest management.

Attempts have been made to collect and analyze spore types present in airborne inocula of *H. annosum.* We made collections at two forest sites in northwest Oregon from September through November with a vacuum device that pulls air through a nucleopore filter. The filters were removed and prepared for viewing with the SEM. Basidiospores of *H. annosum* were observed but conidia were not. In contrast, Leslie (1983) determined, by using similar collection procedures and our SEM techniques (Florance *et al.* 1981, Shaw and Florance 1979), that 18 percent of the *H. annosum* spores deposited in October at a site in coastal Washington state were conidia. If Leslie's (1983) contention that conidia of *H. annosum* are more resistant than basidiospores to heat and dessication is correct, then the moderately high level of conidia in airborne inocula could be significant to disease development in Pacific Northwest forests.

Both of these data sets are very preliminary and many more sampling attempts need to be made before definitive results can be obtained; however, such information should be useful to researchers in the expanding field of aerobiology. Scanning electron micrographs of specific basidiospores also should help to clarify uncertainties in some current taxonomic descriptions.

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Distribution and Amount of Four Knapweed (*Centaurea* L.) Species in Eastern Washington[1]

Abstract

Since their introduction in the early 1900's, four knapweed (*Centaurea* L.) species have become prominent weeds of pastures, rangeland, and nonirrigated hay in the Northern Intermountain Region. The reduction in forage following invasion by these weeds threatens the stability of the ranching industry. Planning an effective integrated control program requires information on the distribution and amount of each species. An eastern Washington knapweed survey was completed in 1987.

Diffuse knapweed (*Centaurea diffusa* Lam.) was reported in all 20 eastern Washington counties, for a total of 173, 151 ha of infested area. Ninety percent of the infestation was in the six counties that border the Columbia River Basin to the north and west: Stevens, Ferry, Okanogan, Chelan, Kittitas, and Yakima. Of the 16 counties reporting yellow starthistle (*C. solstitialis* L.), those 5 in southeastern Washington had 93 percent of the 54,172 ha. A total of 10,777 ha of spotted knapweed (*C. maculosa* Lam.) was reported from 19 counties. Ninety-two percent was reported from the northeastern counties of Spokane, Pend Oreille, and Stevens. Russian knapweed (*C. repens* L.), reported from 19 counties, was estimated at 3,259 ha.

The annual loss in forage production on pasture and rangeland was estimated to be 59,190,540 kg, a value of $951,000 in Animal Unit Months or $2.9 million in hay.

Introduction

During the past quarter century, populations of several *Centaurea* species expanded on rangelands of the Northern Intermountain Region of North America. They pose a serious threat to the stability of the ranching industry. Forage production on rangeland was reduced as perennial bunchgrasses were replaced by downy brome (*Bromus tectorum* L.[2]). Although undesirable for various reasons (e.g., extreme production cycles, short grazing period, and fire hazard at maturity), downy brome is highly palatable to livestock in its flush of early growth. The low palatability of the knapweeds creates a much more serious type of range deterioration (Roché *et al.* 1986).

Although 14 species of *Centaurea* have been collected in Washington (Roché and Talbott 1986), the important species in eastern Washington are yellow starthistle and diffuse, spotted, and Russian knapweed. The rosettes of yellow starthistle (*C. solstitialis* L.) and spotted and diffuse knapweeds (*C. maculosa* Lam. and *C. diffusa* Lam., respectively) are not readily grazed. Popova (1960) noted that although the rosettes of the first year's growth of diffuse knapweed are nutritious and edible, "they are strongly appressed to the ground, as if fastened to it, and are difficult for cattle to get at, even for sheep in snow-free winters." Mature knapweeds are fibrous; yellow starthistle has sharp spines on the seed heads. Coarse dense stems and spines limit access by grazing animals to associated forage species. In addition, yellow starthistle and Russian knapweed (*C. repens* L.) are poisonous to horses (Kingsbury 1964, Young *et al.* 1970).

Because they are unpalatable, knapweeds greatly reduce dryland forage production, whether hay, range, or pasture. In British Columbia, the loss in forage production due to diffuse and spotted knapweed is estimated at $320,000 annually which equates to a theoretical loss in beef output value of over $1.5 million (Cranston 1985). Spotted knapweed causes an estimated $4.5 million forage loss annually to the Montana range livestock industry (Lacey *et al.* 1986).

Other losses include soil erosion, and reductions in wildlife populations, recreation and property values (Cranston 1985). In Montana, it was estimated that the rate of soil erosion doubled when spotted knapweed replaced perennial bunchgrass on rangeland (French and Lacey 1983).

[1]Scientific Paper No. 7936. Contribution from the College of Agriculture and Home Economics Research Center, Washington State University. Project 0211.
[2]Scientific names follow Hitchcock and Cronquist 1976.

The need for a survey of knapweed distribution in Washington has been evident for at least two decades. In 1958 the westward movement of spotted knapweed from Montana along railroad and highway rights-of-way was recognized, and a survey of acreages by county was suggested to assist in gaining program support (Roché 1985). In December 1984, an interagency meeting held at Washington State University led to the formation of a Knapweed Steering Committee. This committee was assigned to "evaluate alternatives and recommend an integrated knapweed control program" (Roché 1986). This paper reports the results of the first, and essential, step in such a program, a survey of the four major species by amount, location, and relative dominance (Talbott 1987).

Methods and Materials

The location and amount of each species of knapweed was estimated by soliciting data from professionals interested in weed control in the 20 counties east of the Cascade Mountains in Washington. In 1984, survey cards, an explanation of the survey, and a discussion of the knapweed problem were sent to personnel in Cooperative Extension, County and District Weed programs, Soil Conservation Service, and public land management agency personnel (e.g., Forest Service, Bureau of Land Management, Bureau of Indian Affairs, and Washington State Departments of Natural Resources and Wildlife). We requested the following information for each of the four species: area infested, dominance rating of the weed, current land use, and location. Estimates of area and dominance rating of the weed were the only quantitative factors. The cooperators were instructed to estimate infestation size as the area that would require treatment. The dominance scale of 1 to 5 (Table 1) is slightly modified from Poulton (1962). Density, which requires time-consuming counting of individuals in a definite space, was not used: it is often impossible to count individuals for plants which reproduce vegetatively and the size of mature individuals may vary a thousand fold under different growing conditions (Daubenmire 1968). Dominance based on occupancy of space indicates the relative influence that a species exerts on the other components. In addition to the ease in recording the relative amount of the weed, relative forage reduction can be estimated from the dominance rating.

Participation in the survey was voluntary; thus some infestations were missed because the individuals chose not to participate in the survey. Other infestations were missed because there was not sufficient time or personnel to cover the entire area. The completeness of the survey as a percentage of the land area in each county is estimated for each species in the results section. Survey cooperators are listed by county in the Acknowledgments.

The survey was done in varying intensities. In some counties it was a systematic search for knapweed (Adams, Ferry, Franklin, Klickitat, and Stevens); in other counties it was the best recollections of individuals familiar with the area

Table 1. Dominance rating definitions[1]

Dominance	Definition	Estimated Forage Reduction (%)
1	It can be found by searching in and around other species. A "1" is not obvious.	5
2	It can be seen only by moving through the vegetation or by searching for it while standing in one place. A patchy pattern observed by moving through the vegetation rates a "2."	10
3	It is easily seen by standing in one place and glancing around, but it is not an obvious dominant. In a mixed stand several species may fall into this category.	40
4	It is at least a codominant. It shares dominance relative to cover or is considered slightly subordinate to other species, native or introduced; for example: cheatgrass, Kentucky bluegrass (*Poa pratensis* L.), bunchgrass range or a mixture of weeds on abandoned farmland.	60
5	It dominates the site. It is dominant in the sense that it provides essentially total cover when viewed casually.	95

[1]Modified from Poulton 1962

combined with some systematic search and noting of weed locations while doing county weed inspection or other work (Asotin, Chelan, Columbia, Douglas, Garfield, Grant, Kittitas, Lincoln, Okanogan, Pend Oreille, Spokane, Walla Walla, Whitman and Yakima). In Benton County, there was no county-wide coordination of the survey. The Hanford Reservation, U and I Group, Chateau Ste. Michelle, and U.S. Fish and Wildlife Service lands were surveyed. Other locations were infestations the cooperators happened to notice.

Survey cards were completed only when weeds were found. The minimum amount for a card was one plant. There was no maximum limitation although the surveyors were encouraged to report by dominance rating for each site, thereby discouraging a county lump sum approach. Surveyors were not limited to a set number of cards. Additional cards were sent as requested. In some instances, a less detailed survey was accepted because it was the only information available. The number of survey cards returned were 4,142 for diffuse knapweed, 838 for yellow starthistle, 700 for Russian knapweed, and 425 for spotted knapweed.

Weed locations were plotted on U.S. Geological Survey 1:100,000 topographic maps. Map locations were numbered to correspond with the site number on the survey card. Duplicate reports were avoided by comparing new reports with previously recorded sites on the base maps. Base maps were digitized to produce computer-plotted maps. These maps along with summaries of amount, dominance rating, and land use by species were sent to each county at the beginning of the second field season. This progress report facilitated the addition of new sites and the completion of the survey with a minimum of duplication of effort.

Survey work continued through the 1986 field season. A report was sent to each county coordinator (weed supervisor and/or Cooperative Extension agent) in early 1987 for approval or corrections.

Results and Discussion

This is the most thorough survey attempted to date on a set of weed species in eastern Washington. Lower amounts of knapweed were reported in this survey, which required precise locations, than in previous surveys which were subjective broad estimates. Two previous weed surveys in Washington by Roché (1967) and Penhallegon (1983) included knapweed species. Results of the three surveys follow: for diffuse knapweed, 150,674 ha (1967), 274,062 ha (1983), and 173, 151 ha (1987); for yellow starthistle, 10,288 ha (1967), 62,057 ha (1983), and 54,172 ha (1987); for spotted knapweed, 28,900 ha (1967), 79,882 ha (1983), and 10,777 ha (1987); and for Russian knapweed, 41,252 ha (1967), 15,962 ha (1983), and 3,259 ha (1987).

Diffuse Knapweed

Diffuse knapweed grows in every eastern Washington county (Table 2, Figure 1). It was by far the most abundant species, occupying 72 percent of the total area reported for the four species. The total of 173,151 ha is an underestimate because the survey was not completed in Adams (80%), Benton (20%), Grant (80%), Okanogan (50%), and Yakima (60%) counties. Five counties (Okanogan, Ferry, Yakima, Kittitas, and Stevens) each reported more than 12,000 ha. Including Chelan, the six counties which border the Columbia River Basin to the north and west had 90% of the diffuse knapweed reported for eastern Washington (Figure 1, Table 2).

Table 2. Infested area in each county by species, in hectares.[1]

	Diffuse knapweed	Yellow star-thistle	Spotted knapweed	Russian knapweed	Total
Adams	264	24	56	333	677
Asotin	270	2,223	trace	28	2,521
Benton	1,232	12	trace	43	1,287
Chelan	5,779	2	1	85	5,867
Columbia	12	17,956	1	2	17,971
Douglas	3,104	0	0	86	3,190
Ferry	23,696	336	69	278	24,379
Franklin	103	19	4	160	286
Garfield	179	858	127	12	1,176
Grant	553	0	6	281	840
Kittitas	13,483	trace	59	175	13,717
Klickitat	2,936	2,512	3	38	5,489
Lincoln	683	0	362	106	1,151
Okanogan	79,402	527	80	1,081	81,090
Pend Oreille	98	0	518	0	616
Spokane	1,468	4	9,061	8	10,541
Stevens	12,534	153	378	47	13,112
Walla Walla	233	25,422	4	33	25,692
Whitman	5,308	3,852	29	20	9,209
Yakima	21,814	272	19	443	22,548
TOTALS	173,151	54,172	10,777	3,259	241,359

[1]Multiply by 2.47 to convert to acres.

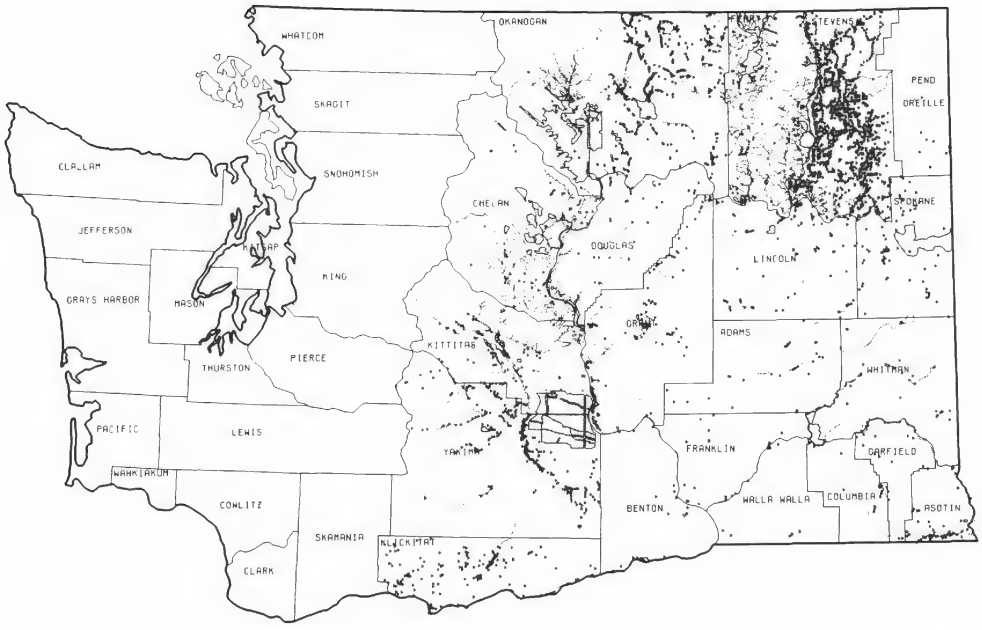

Figure 1. Distribution of diffuse knapweed in eastern Washington. Sites were plotted as points, lines or areas. Each indicate only presence of the weed. A point may indicate one plant up to 65 ha. Lines indicate stringers along roads, rivers, power lines, or railroads. Area is indicated when detailed mapping of individual sites was not done.

Every county reported diffuse knapweed along roadsides and railroads, for a total of 13,096 ha, or 7.6 percent of the total. This "tumble knapweed" has spread along roadsides, gaining wide distribution. Plants carried or blown by vehicles lose seeds gradually from the urn-shaped heads (Watson and Renney 1974). Transportation routes through pasture, rangeland, and timbered range have served as a source of infestation for entire areas.

Rivers and streams also transport diffuse knapweed, often into areas not accessible by vehicle. We have observed the bushy stalks floating in rivers and plants growing on gravel bars and sandy shores. Diffuse knapweed was found along the Okanogan, Methow, Yakima, Snake, Grande Ronde, Columbia, and other rivers.

From rivers and rights-of-way, diffuse knapweed has moved onto rangeland. Eighty percent (138,297 ha) of the diffuse knapweed in eastern Washington was reported on pasture, range, and timbered range (Table 3). Of this total, 7 percent was pasture, 35 percent was timbered range, and 58 percent was rangeland. Infested rangeland represents about 5 percent of the total rangeland in eastern Washington (Washington Rangeland Committee and Washington Conservation Commission 1984). The percentage of rangeland in each county infested by diffuse knapweed varied, but Ferry County reported the highest level (31%), followed by Okanogan and Stevens counties.

Dominance rating of the weed generally increased with site disturbance. Abandoned cropland and industrial sites were commonly dominated by diffuse knapweed (rating 5). Overall, 38 percent of the diffuse knapweed was reported as dominance ratings 1 and 2, while dominance ratings 3, 4, and 5 were estimated at 23, 25, and 14 percent, respectively (Table 4).

Yellow Starthistle

The 54,172 ha of yellow starthistle was 22 percent of the total area reported for the four species. Four counties (Douglas, Grant, Lincoln, and Pend Oreille) reported no yellow starthistle.

TABLE 3. Infested area by current land use by species, in hectares.

Current Land Use	Diffuse Knapweed	Yellow Star-thistle	Spotted Knapweed	Russian Knapweed
cropland	1,601	29	28	510
edge of cropland	1,307	6,217	177	162
abandoned cropland	2,506	314	32	323
pasture	9,732	935	1,217	333
rangeland	80,359	44,663	398	1,206
timbered range	48,206	81	185	1
clearcut	213	0	0	0
recreational area	1,176	204	171	75
urban/residences	1,158	186	2,403	46
industrial sites	2,472	125	4,253	24
roadside/railroad	13,096	307	724	339
skid road	4,974	0	6	0
parking area	253	49	6	3
speculation	1,728	22	1,052	35
idle land	3,801	1,033	119	162
other	43	0	6	3
irrigation r/w, river	526	7	4	38

TABLE 4. Infested area by species and dominance rating category, in hectares.

	Dominance Rating				
	1	2	3	4	5
Diffuse knapweed	38,923	26,874	39,825	43,288	24,241
Yellow starthistle	2,292	11,880	15,506	22,211	2,283
Spotted knapweed	29	269	3,407	6,554	519
Russian knapweed	16	50	490	1,136	1,567

The yellow starthistle survey is estimated to be 90 percent to 100 percent complete for all counties. Better records were available for this species because a cost-share control program has been available since the early 1970's. Locations of weed control projects funded one third each by the state, county and landowner were documented by county weed supervisors.

Yellow starthistle was concentrated in the southeastern corner of the state: 80 percent occurred in Columbia and Walla Walla counties (Table 2, Figure 2). These two counties, along with Asotin, Garfield, and the southern part of

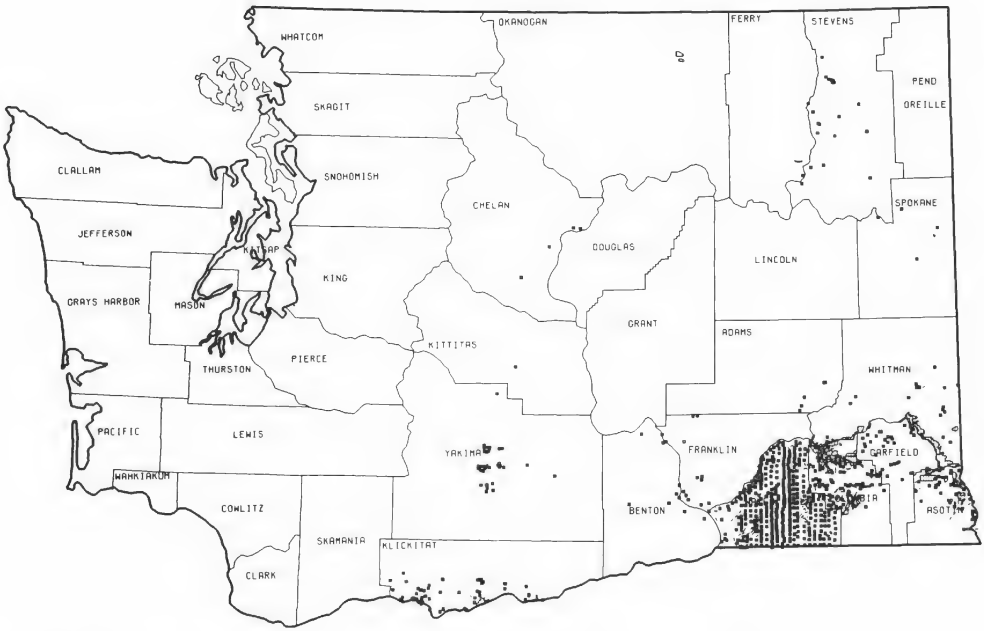

Figure 2. Distribution of yellow starthistle in eastern Washington. Symbols as in Figure 1.

Whitman County, had 93 percent of the yellow starthistle in eastern Washington. The remaining sites fit one or more of five categories: (1) sunny, warm south-facing slopes along the Columbia River, (2) seeded along with alfalfa or clover, (3) along irrigation ditches, (4) in overgrazed pastures, or (5) a ranch with branch operations in southeastern Washington. A small population persisted on both sides of the Columbia River at the old Hanford townsite ferry crossing. In Klickitat, Ferry, and Stevens counties, the yellow starthistle was found on natural grasslands along the Columbia River or in dryland alfalfa. The approximately 500 ha in Okanogan County was seeded in 1985 with contaminated crimson clover broadcast over a wildfire area. The yellow starthistle in Adams County occurred where the landowners have moved equipment or livestock in from Columbia County.

Yellow starthistle is primarily a rangeland weed. Eighty-four percent of the infested area was pasture, range, or timbered range (456,679 ha), with 98 percent of that on rangeland (Table 3). This constituted about 2 percent of the total rangeland in eastern Washington (Washington Rangeland Committee and Washington Conservation Commission 1984). The percentage of rangeland infested in Walla Walla and Columbia counties was much higher, 41 and 25 percent, respectively.

The movement of yellow starthistle along roadsides, railroads, and rivers has been more limited than diffuse knapweed. Fourteen counties reported some yellow starthistle along roadsides or railroads, but the amount (307 ha), 5 percent of the total, was the lowest of the four knapweeds. Seed of yellow starthistle growing in gravel pits has been distributed along roadsides and at new construction sites (dams, parking lots, substations, powerlines, roads).

Contaminated seed and feed have been the most important means of spread of yellow starthistle. The seed industry considered the *Centaurea* species in the West as the most difficult type of seeds (i.e., weight, size, shape, etc.) to remove from alfalfa seed (Roché 1965). Most of the infested 30 ha reported on cropland was in alfalfa. Most of the "edge of cropland" area (215 ha in Columbia County and 5,951 ha in Walla Walla County) was adjacent to grain crops. These were the eyebrows or "outground," some of which was previously farmed.

Yellow starthistle occurred as a codominant (rating 4) on 41 percent of the total infested area. Dominance ratings 1 and 5 were each reported as 4 percent, while dominance ratings 2 and 3 comprised 22 and 29 percent, respectively (Table 4). In Columbia and Walla Walla counties, dominance ratings increased with elevation: ratings 4 and 5 were more common in the foothills of the Blue Mountains, with ratings 1 through 3 prevalent near the Snake River, except in disturbed areas such as abandoned cropland or industrial sites.

Spotted Knapweed

Spotted knapweed was reported from 19 eastern Washington counties for a total of 10,777 ha (Table 2). None was found in Douglas County. The survey information is estimated to be 90 percent complete except for Benton (10%), Grant (80%), and Yakima (50%) counties.

Spotted knapweed ranked third of the four species with only 4 percent of the total area infested by the four species. Ninety-two percent of the spotted knapweed was found in Spokane, Stevens, and Pend Oreille counties (Figure 3).

Seventeen percent of the spotted knapweed was reported on pasture, range, and timbered range (Table 3). Sixty-eight percent of the pasture-range-timbered range total was pasture. Spotted knapweed was a common pasture weed in Spokane and Pend Oreille counties and occurred in dryland alfalfa in Stevens, Pend Oreille, Kittitas, and Spokane counties. Approximately 2 percent of the spotted knapweed was reported on abandoned cropland. This figure includes areas that are listed in Table 3 under other land uses such as pasture, idle land, or edge of crop, for which the surveyors indicated on the card were also abandoned cropland.

All counties reporting spotted knapweed found it along roadsides and railroads, 724 ha or 7 percent of the total. Counties with low levels of spotted knapweed found it almost exclusively on roadsides and in urban areas. For example, it was reported in Chelan County only along Highway 2 near Stevens Pass, along a powerline access road south of Wenatchee, and in Leavenworth.

Thirty-nine percent (4,253 ha) grew on industrial sites. The single largest infested industrial area was in the Spokane Valley. The acreage

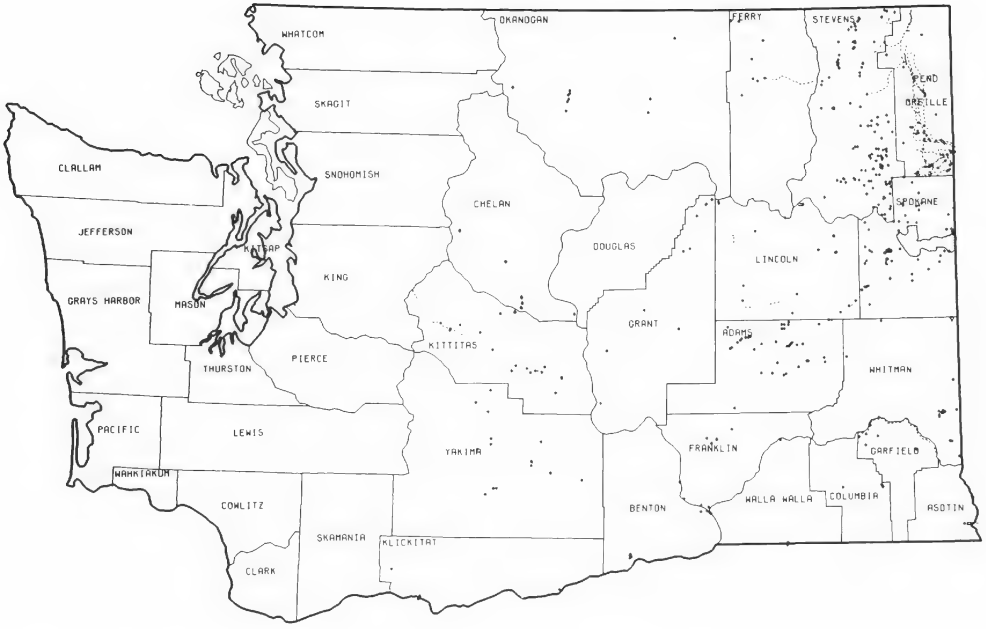

Figure 3. Distribution of spotted knapweed in eastern Washington. Symbols as in Figure 1.

listed as industrial sites included gravel pits and stockpiles, power lines, grain elevators, railroad, and equipment yards. These are strategic seed distribution points because of the volume of traffic and movement of materials which can carry seeds to new locations.

Ninety-three percent of the spotted knapweed was reported as dominance ratings 3 and 4 (Table 4). Many of the spotted knapweed sites were reported as scattered plants (dominance ratings 1 and 2). Although low in dominance as well as total acreage, their relative importance should not be underestimated. The potential rate of expansion of many widely scattered small infestations is greater than for the same size infestation in a single location.

Russian Knapweed

The total area reported for Russian knapweed was 3,259 ha (Table 2). Only Pend Oreille County had no Russian knapweed. The survey was incomplete for Adams (80%), Benton (20%), Grant (60%), Okanogan (50%), and Yakima (60%) counties. Because Russian knapweed generally grows as small dense patches and does not spread rapidly, it has often been overlooked, especially on non-cropland. Russian knapweed was widely scattered, but most was found in the Columbia Basin and in the Okanogan and Yakima valleys (Figure 4). Fifty-seven percent of the area reported was in Okanogan, Yakima, and Adams counties (Table 2).

Russian knapweed has spread along railroads and, less commonly, roadsides. Thirteen counties reported this weed on rights-of-way for a combined 339 ha, 1 percent of the total. Movement along roadsides has been less important for Russian knapweed than for the other knapweeds because of lower production of viable seed and because the seeds are held in a cup-shaped head and lose their plume upon maturity (Watson 1980). Fewer seeds are caught on passing vehicles, either as individuals like spotted knapweed and yellow starthistle or as intact stalks like diffuse knapweed. Larger quantities of seed are needed to establish a new infestation when seed viability rates are low.

The amount reported on cropland (510 ha) was 16 percent of the total. Many infestations

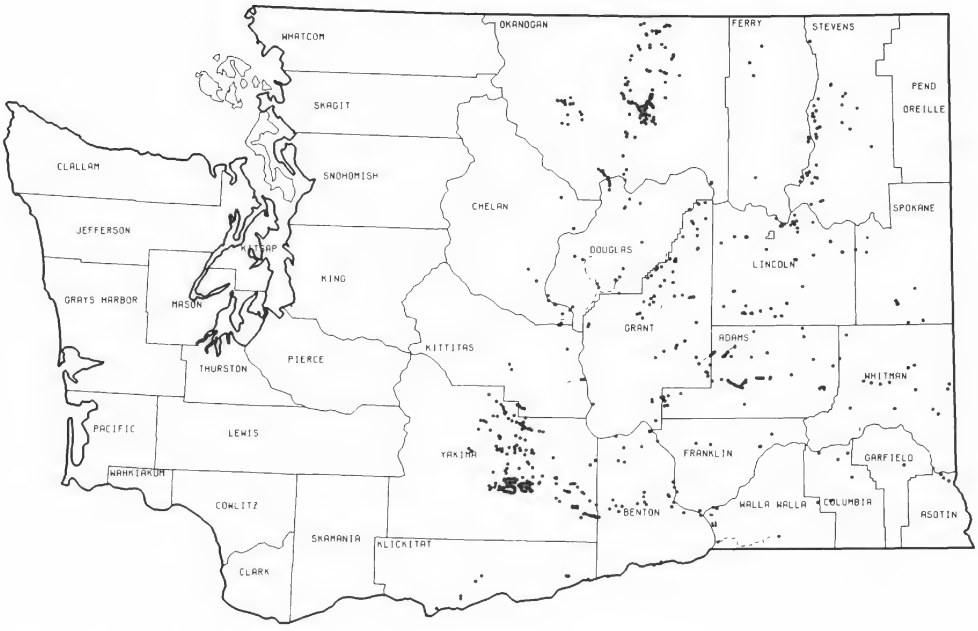

Figure 4. Distribution of Russian knapweed in eastern Washington. Symbols as in Figure 1.

were caused by contaminated crop seed, usually alfalfa or sugar beet seed (Noxious Weed Control Task Force 1952, Robbins *et al.* 1951).

Forty-seven percent of the Russian knapweed was reported on range and pasture (Table 3). Much of the pasture was irrigated or bottomland. Russian knapweed tolerates poor drainage, heavy soils, and saline/alkaline conditions (Watson 1980).

Russian knapweed shoots, except seedlings, develop from stem buds on horizontal roots. Under favorable conditions Russian knapweed forms dense stands that crowd out other vegetation. It is not surprising then, that 83 percent was reported as dominance ratings 4 and 5 (Table 4).

Conclusions

Attempts to control knapweed species have led to large expenditures of private and public funds. At times, these costs have exceeded the productive potential of the land. Money spent in control programs should be offset by reductions in losses or potential losses.

Losses in forage production in eastern Washington are estimated here by multiplying the infested area (Table 5) by production per unit area, a utilization factor, and a forage reduction factor based on dominance rating of the weed (Table 1). In the computation we assumed 50 percent utilization and average annual forage production for good condition pasture at 5,625 kg/ha (5,000 lb/ac), for good condition rangeland at 1,125 kg/ha (1,000 lb/ac), and for good condition timbered range at 1,462 kg/ha (1,300 lb/ac). This average annual forage production was estimated for representative range sites, habitat types and soil series where the weeds were found (Talbott 1987) by consulting tables and descriptions in soil survey reports (Beieler 1975, 1981; Donaldson 1980; Donaldson *et al.* 1982; Donaldson and Giese 1968; Harrison *et al.* 1964; Lenfesty 1980; Zulauf and Star 1979) and productivity estimates for plant associations in Steppe Vegetation of Washington (Daubenmire 1970). The knapweed species were uncommon on coarse textured, excessively drained range sites and shallow range sites (Talbott 1987), so the estimates are based on normal production for loamy range sites.

TABLE 5. Species by dominance rating on pasture and rangeland, in hectares.

	1	2	3	4	5
Pasture					
Diffuse knapweed	948	335	2,821	3,107	2,519
Yellow starthistle	40	19	521	370	8
Spotted knapweed	0	50	107	937	119
Russian knapweed	1	5	42	105	194
Pasture total	989	409	3,491	4,519	2,840
Range					
Diffuse knapweed	21,160	15,877	11,863	18,895	12,480
Yellow starthistle	1,710	10,689	10,006	19,930	2,272
Spotted knapweed	22	88	43	112	133
Russian knapweed	2	15	221	508	458
Range total	22,894	26,669	22,133	39,445	15,343
Timbered Range					
Diffuse knapweed	13,540	7,950	14,280	10,306	2,130
Yellow starthistle	0	19	56	4	0
Spotted knapweed	0	4	55	117	8
Russian knapweed	0	0	0	0	1
Timbered range total	13,540	7,973	14,391	10,427	2,139

On pasture, the annual loss in forage production due to the four knapweeds species is 19,288,523 kg (42,434,750 lbs), the equivalent of 21,217 tons of hay or 42,435 AUMs.[3] Comparable values for rangeland are 28,577,591 kg (62,870,700 lbs): 31,435 tons of hay or 62,870 AUMs and for timbered range, 11,324,426 kg (24,913,737 lbs): 12,457 tons of hay or 24,914 AUMs. Using a value of $45 per ton for hay fed as replacement forage (Doug Warnock, Kittitas County Extension Chairman, pers. comm.), the estimated annual additional cost due to knapweed is $2.9 million. Using a value of $10 per AUM on pasture (Doug Warnock, pers. comm.) and $6 per AUM on rangeland (Eric Anderson, Range Conservationist, Yakima Firing Center, pers. comm.), the estimated annual loss is $951,000.

The results of the survey and subsequent mapping can be used to design weed control strategies. Distribution and relative dominance suggests practical levels of effort ranging from containment to eradication. Data of the type reported can provide the basis for understanding and cooperation among the several interest groups.

[3]Animal Unit Month, the forage requirements of one cow or five sheep, for one month, here defined as 1,000 lbs of air dry forage.

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Distribution, Density, and Size-Class Structure of Dungeness Crabs in the River-Dominated Columbia River Estuary

Abstract

Dungeness crabs, *Cancer magister,* are important to the large west coast commercial fishing industry, and estuaries are important habitats for the crabs. To better understand the basic dynamics of crab populations, we studied the distribution, density, and size-class structure of Dungeness crabs in the Columbia River estuary (Oregon and Washington) monthly from November 1983 through October 1985. Crabs were generally distributed from the bar (mouth of the estuary) to River Kilometer 28. Overall, crab densities on the bar (mean = 210 ± 1061 (SD) crabs/hectare) were significantly less than densities upstream from the bar (mean = 395 ± 1844 crabs/hectare). Densities on the bar were greatest in spring and summer when young-of-the-year (0+ age) crabs were relatively abundant. Densities of crabs on the bar were significantly greater during the second year of the study (mean = 391 ± 1483 crabs/hectare) than during the first year (mean = 28 ± 53 crabs/hectare). In areas upstream from the bar, densities were not significantly different between the two years; generally, there were no significant seasonal differences among upstream densities. Zero+ age crabs were captured in the estuary beginning in May of both years; no 0+ age crabs were collected in intertidal areas of the estuary. Densities of 0+ age crabs on the bar increased during late spring and summer; however, there was no corresponding increase in densities upstream from the bar. Our data indicate that the Columbia River estuary provides valuable habitat for Dungeness crabs, particularly for crabs <130 mm in carapace width.

Introduction

The Columbia River estuary, one of the major estuaries in Washington and Oregon, has high numbers of Dungeness crabs, *Cancer magister* (Emmett and Durkin 1985). Dungeness crabs support an important commercial fishery in coastal areas of Washington and Oregon; during the 1982-83 commercial season, which was a poor season, coastal landings in Washington and Oregon exceeded 3.6 million kg (Pacific Marine Fisheries Commission 1984).

Researchers working in other west coast estuaries have noted the value of estuarine areas to Dungeness crabs. Orcutt (1977) estimated that up to 80 percent of the Dungeness crab population offshore from San Francisco, California, used the San Francisco-San Pablo Bay complex at some time. Stevens and Armstrong (1984) found that both subtidal and intertidal areas of Grays Harbor estuary, Washington (about 80 km north of the Columbia River estuary) supported large numbers of Dungeness crabs. They observed that Grays Harbor was used as a nursery area, and estimated that crabs reared in the estuary could provide a substantial contribution to the offshore commercial fishery.

Initial studies of Dungeness crabs in the Columbia River estuary showed an extensive population of crabs and also identified the temporal occurrence of 0+ age crabs (young-of-the-year) (Emmett and Durkin 1985). However, a comprehensive study of Dungeness crabs in the estuary was needed to provide data that could be used to assist in reducing the impact of dredging activities in the estuary. Specific objectives of our study were to describe distribution, abundance, and size-class structure of Dungeness crabs in the Columbia River estuary.

Methods

Study Area

Unlike many other west coast estuaries, the Columbia River estuary is a river-dominated system. The Columbia River estuary, a drowned river mouth, is strongly influenced by river flows. The highest flows typically occur in the spring, the lowest during late summer and fall. During the study period, estimated flows (monthly averages) ranged from 3,121 m^3/s in August 1985 to 14,091 m^3/s in May 1985 (estimates supplied by U.S. Geological Survey, Portland, Oregon). Estuarine salinities fluctuate widely depending upon river

flow, tidal stage, and distance from the ocean (Neal 1972). Salinity intrusion is generally lowest during the spring (highest river flows) and greatest during late summer and fall (lowest river flows). During low-flow seasons (about 4,400 m^3/s), minimum bottom salinities in most of the lower 22 km of the estuary range from 0.5 to 15.0 ppt, with maximum salinities $\geq$30 ppt. Minimum bottom salinities in much of the lower 22 km of the estuary reach 0.0 ppt during high-flow seasons (about 8,800 m^3/s) (Jay 1984).

Sampling

Sampling was done from November 1983 through October 1985. A maximum of 22 estuarine sites were sampled each month (Figure 1). Because crabs were not captured upstream from Stations 15 and 18 in past surveys, these two stations were not always sampled if less than two crabs were collected at nearby downstream sites. In November 1984, the location of Station 10 was moved about 1.6 km west to avoid bottom obstructions at the original site.

An 8 m semiballoon shrimp trawl, with overall mesh size of 38.1 mm (stretched), was used at 20 of the sampling sites. A 9.5 mm mesh liner was inserted in the cod end of the net to ensure retention of 0+ age crabs. Fishing width of the trawl was estimated by the manufacturer to be about 5 m. Trawling at each site in the estuary was generally done for 5 min during times of higher salinity (early flood to early ebb tide). Distance traveled during a sampling effort was estimated using either a radar range-finder or Loran-C navigational equipment. Two intertidal sites in Baker Bay were sampled (when exposed) by walking along transects perpendicular to shore. The vegetation and substrate along these transects were examined for crabs.

Generally a subsample of at least 100 crabs ($\geq$20 mm) from each sample was measured (mm) across the carapace anterior to the 10th anterolateral spines, weighed (g), sexed, and checked for eggs and the nemertean *Carcinonemertes errans,* which is an egg predator (Wickham 1979, McCabe *et al.* 1987). Crabs not individually measured and weighed were counted. When large numbers of early instar crabs (< 20 mm) were captured, a minimum of 50 were measured and weighed. Size variations of the early instar crabs were much less than those of the larger crabs.

Salinity (ppt) and temperature (°C) were measured at the surface and near the bottom before each sampling effort using a Beckman

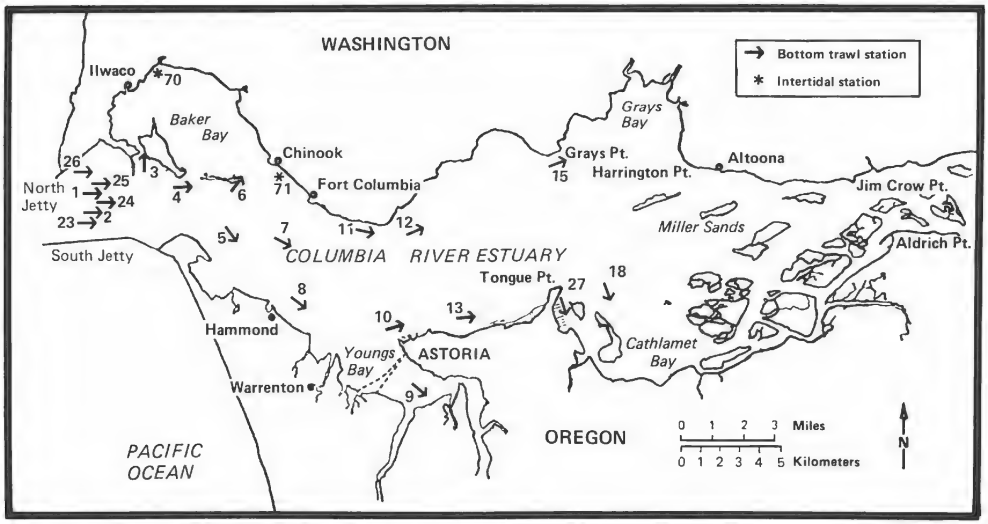

Figure 1. Map of the Columbia River estuary, showing sampling sites for the 2-year Dungeness crab study.

RS5-3 salinometer and temperature probe (Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA).

Data Analysis

Using catch data, fishing width of the trawl (5 m), and distance traveled during sampling, we estimated the density of crabs (number/hectare) at each station for each month. Crab densities were calculated for four size classes: Size Class I (<50 mm), Size Class II (50-99 mm), Size Class III (100-129 mm), and Size Class IV (≥130 mm).

Various statistical tests were used to analyze the data. Comparisons of crab densities were made using the nonparametric Mann-Whitney U-test and Kruskal-Wallis test (Elliott 1977). For making seasonal comparisons, the seasons were defined as: winter—January, February, and March; spring—April, May, and June; summer—July, August, and September; and fall—October, November, and December. Densities at the mouth of the estuary [bar (Stations 1, 2, 23-26)] were compared with densities in the area upstream from the mouth (Stations 3-8 and 10-12). Regression, both simple and multiple, was used to examine relationships between density and physical parameters (bottom salinity and temperature). Densities were transformed to $\log_{10}$ (number/ hectare + 1) prior to employing regression.

Results

Crabs were generally distributed from the mouth of the estuary to about River Kilometer (RKm) 28 throughout the 2-year study. The farthest upstream distribution of crabs occurred during winter of both years when Size Class I crabs were captured at Station 15 (Rkm 32). No crabs were captured in Youngs Bay (Station 9), Cathlamet Bay (Stations 18 and 27), or intertidal areas of Baker Bay; crabs were captured infrequently at Grays Point (Station 15) and off central Astoria (Station 13). Because crab numbers were generally zero at the aforementioned stations, these stations were not included in density comparisons.

Crab densities (all size classes combined) in the estuary varied considerably among individual stations; also, monthly densities at individual stations frequently varied (Figures 2, 3). Overall, crab densities on the bar (mean = 210 ± 1061 (SD) crabs/hectare) were significantly less than densities in the estuary upstream from the bar (mean = 395 ± 1844 crabs/hectare) (Mann-Whitney, $P<0.001$). On a seasonal basis, densities on the bar were significantly less than densities in the upstream area during fall and winter of both years (Mann-Whitney, $P<0.05$); however, there were no significant differences between the two areas during spring and summer of both years (Table 1).

TABLE 1. Seasonal mean densities (number/hectare) of Dungeness crabs (all size classes combined) on the Columbia River bar and in the estuary upstream from the bar; standard deviations are also shown. See text for season descriptions.

Year	Season	Bar	Upstream
1983	Fall	5.7 ± 10.2	744.7 ± 1284.5
1984	Fall	25.4 ± 22.5	103.3 ± 138.7
1984	Winter	3.5 ± 6.7	122.0 ± 174.9
1985	Winter	27.0 ± 43.0	127.9 ± 161.4
1984	Spring	58.2 ± 75.9	64.2 ± 97.3
1985	Spring	659.3 ± 2022.6	181.2 ± 432.6
1984	Summer	43.9 ± 57.8	164.3 ± 291.2
1985	Summer	839.0 ± 2127.8	1171.5 ± 3701.5

On the bar, densities during the second year (mean = 391 ± 1483 crabs/hectare) were significantly greater than during the first year (mean = 28 ± 53 crabs/hectare) (Mann-Whitney, $P<0.001$). For both years, combined and separate, densities among the seasons on the bar were significantly different (Kruskal-Wallis, $P<0.001$), with the highest densities in spring and summer (Table 1).

In the area upstream from the bar, there was no significant difference in densities between the two years (Mann-Whitney, $P<0.05$). Mean densities for the two years were 221 ± 593 crabs/hectare and 570 ± 2539 crabs/hectare, respectively. Upstream from the bar, for both years combined and the second year, there were no significant differences among the four seasons (Kruskal-Wallis, $P<0.05$); however, during the first year there was a significant difference among seasons, with highest densities in fall (Kruskal-Wallis, $P<0.05$) (Table 1).

Crab densities by size class and month were examined for the bar and the estuary upstream from the bar (Table 2). Densities of Size Class

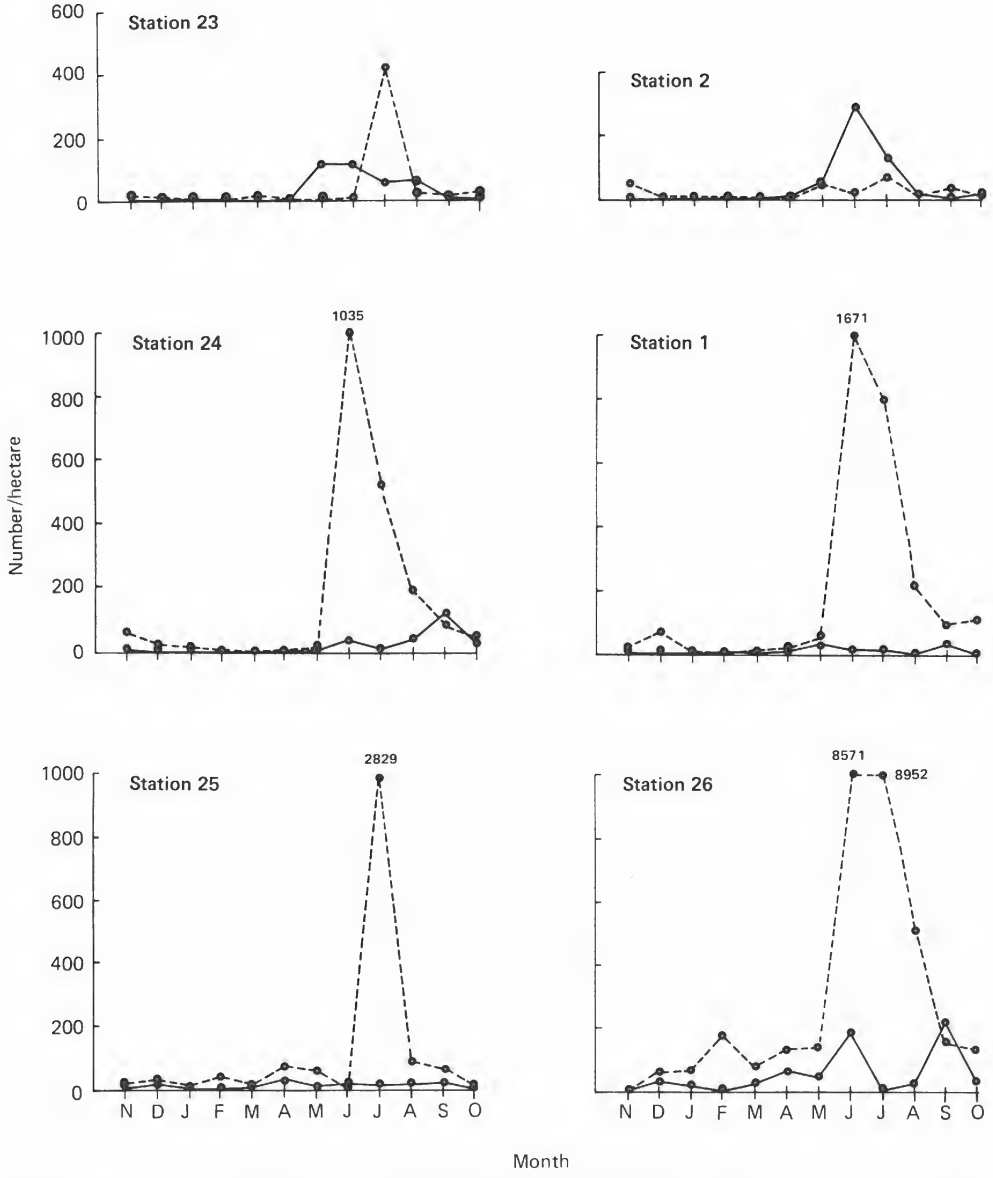

Figure 2. Estimated densities of Dungeness crabs (all size classes combined) at six sampling stations on the Columbia River bar. The solid line represents the first year of the study (Nov. 1983 through Oct. 1984) and the dashed line represents the second year (Nov. 1984 through Oct. 1985).

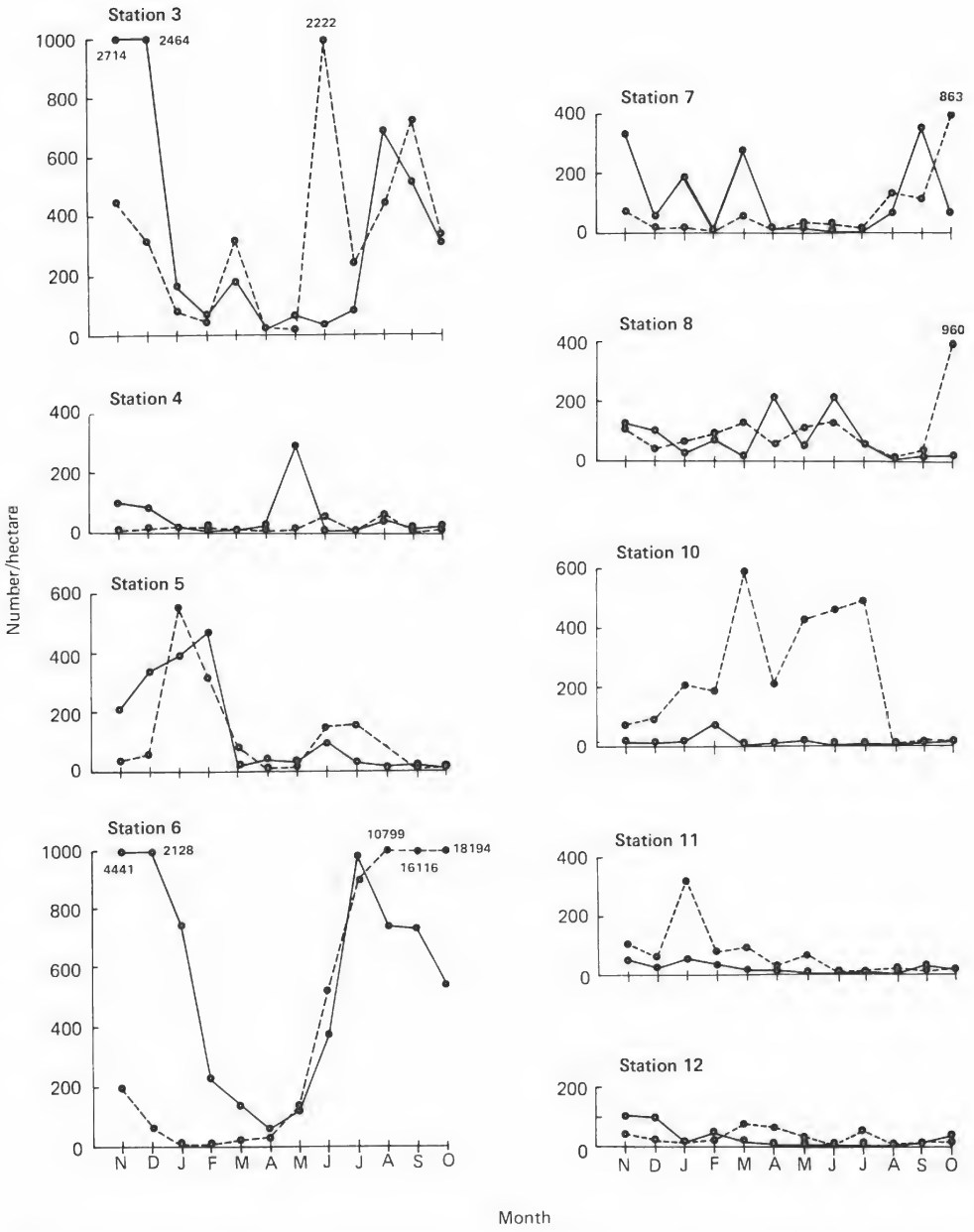

Figure 3. Estimated densities of Dungeness crabs (all size classes combined) at nine sampling stations upstream from the Columbia River bar. The solid line represents the first year of the study (Nov. 1983 through Oct. 1984), and the dashed line represents the second year (Nov. 1984 through Oct. 1985).

TABLE 2. Mean densities (number/hectare) of four size classes of Dungeness crabs on the Columbia River bar and in the estuary upstream from the bar; standard deviations are also shown. See text for size range for each class.

	Size Class I		Size Class II		Size Class III		Size Class IV	
Month	Bar	Upstream	Bar	Upstream	Bar	Upstream	Bar	Upstream
Nov 83	1.4 ± 2.3	15.9 ± 17.1	0.0 ± 0.0	718.2 ± 1350.7	0.0 ± 0.0	154.1 ± 299.9	0.6 ± 1.4	11.1 ± 13.6
Dec 83	2.0 ± 3.4	46.2 ± 98.3	0.0 ± 0.0	437.1 ± 864.9	6.1 ± 10.3	103.5 ± 248.2	1.2 ± 1.9	3.3 ± 6.3
Jan 84	1.4 ± 3.4	46.8 ± 119.6	0.7 ± 1.7	97.2 ± 186.3	0.7 ± 1.6	35.2 ± 55.4	1.4 ± 2.1	0.0 ± 0.0
Feb 84	0.7 ± 1.8	57.4 ± 144.2	0.0 ± 0.0	33.0 ± 45.4	0.7 ± 1.8	18.7 ± 28.0	0.0 ± 0.0	2.4 ± 5.5
Mar 84	3.8 ± 9.3	2.9 ± 4.4	0.0 ± 0.0	48.7 ± 69.6	0.0 ± 0.0	22.5 ± 41.1	1.1 ± 2.6	1.4 ± 4.2
Apr 84	11.0 ± 18.4	5.0 ± 10.4	0.8 ± 2.0	23.5 ± 34.1	5.9 ± 3.9	14.3 ± 35.5	2.8 ± 2.2	1.6 ± 2.4
May 84	13.3 ± 19.6	35.9 ± 87.4	2.8 ± 4.9	22.0 ± 33.0	18.3 ± 27.1	7.8 ± 8.2	10.0 ± 15.0	0.6 ± 1.9
Jun 84	96.2 ± 100.1	2.4 ± 3.9	0.0 ± 0.0	46.6 ± 86.2	3.9 ± 4.5	28.6 ± 45.6	9.7 ± 12.0	4.4 ± 9.1
Jul 84	33.6 ± 51.0	4.3 ± 9.4	0.0 ± 0.0	97.2 ± 253.8	2.7 ± 3.2	27.6 ± 61.0	1.6 ± 2.7	2.1 ± 4.9
Aug 84	6.0 ± 14.7	1.6 ± 3.4	0.0 ± 0.0	93.3 ± 203.0	6.7 ± 11.0	62.7 ± 131.0	15.0 ± 17.1	15.5 ± 30.5
Sep 84	47.9 ± 79.6	4.6 ± 9.6	0.0 ± 0.0	66.3 ± 120.3	8.3 ± 16.6	70.5 ± 107.6	9.7 ± 13.3	47.3 ± 70.5
Oct 84	9.0 ± 10.7	2.8 ± 3.6	0.0 ± 0.0	46.9 ± 99.5	1.9 ± 3.0	48.1 ± 76.1	1.1 ± 2.6	15.4 ± 13.8
Nov 84	16.4 ± 17.6	36.9 ± 34.4	0.0 ± 0.0	43.9 ± 80.5	2.8 ± 4.3	32.9 ± 40.0	9.8 ± 9.5	6.4 ± 6.8
Dec 84	29.9 ± 24.5	43.9 ± 50.2	0.9 ± 2.1	23.5 ± 47.7	2.6 ± 4.8	7.8 ± 6.2	2.0 ± 3.4	1.5 ± 2.3
Jan 85	16.1 ± 23.6	123.6 ± 183.0	0.0 ± 0.0	12.4 ± 20.7	2.6 ± 3.5	4.3 ± 7.4	0.6 ± 1.4	1.8 ± 3.8
Feb 85	37.9 ± 65.4	77.3 ± 107.9	0.0 ± 0.0	5.1 ± 10.5	1.2 ± 2.4	2.7 ± 6.4	0.0 ± 0.0	1.1 ± 2.2
Mar 85	18.0 ± 25.3	106.4 ± 132.4	0.4 ± 1.0	44.4 ± 73.1	2.3 ± 2.7	4.0 ± 5.7	1.8 ± 2.1	0.7 ± 2.0
Apr 85	35.6 ± 49.6	31.2 ± 38.5	0.0 ± 0.0	14.3 ± 27.5	5.1 ± 8.1	2.4 ± 4.0	0.6 ± 1.5	0.5 ± 1.4
May 85	40.9 ± 41.8	38.7 ± 55.1	1.5 ± 2.3	52.3 ± 78.0	5.4 ± 8.6	3.5 ± 4.9	5.1 ± 5.2	1.5 ± 2.3
Jun 85	1876.1 ± 3347.8	62.5 ± 107.0	0.0 ± 0.0	306.0 ± 615.2	1.1 ± 2.6	15.6 ± 19.7	6.5 ± 4.5	15.2 ± 31.4
Jul 85	2250.7 ± 3410.7	31.9 ± 48.3	0.0 ± 0.0	160.9 ± 255.9	1.6 ± 2.6	12.3 ± 30.3	10.4 ± 11.3	9.4 ± 15.9
Aug 85	152.9 ± 153.1	10.8 ± 23.8	16.2 ± 35.1	902.3 ± 2346.1	1.5 ± 2.4	493.7 ± 1370.3	7.0 ± 7.7	28.9 ± 75.7
Sep 85	35.0 ± 29.6	1.4 ± 2.9	33.0 ± 31.8	844.2 ± 2267.8	6.2 ± 4.4	989.3 ± 2915.8	2.4 ± 3.8	58.9 ± 160.5
Oct 85	10.1 ± 12.5	0.0 ± 0.0	27.5 ± 30.8	599.5 ± 1490.7	13.2 ± 15.7	1548.2 ± 4200.6	6.9 ± 10.2	122.0 ± 296.5

I crabs increased on the bar during spring and summer of both 1984 and 1985; overall, Size Class I was the most numerous size class on the bar. Most Size Class I crabs captured on the bar were 0+ age crabs. On the bar, Size Class I crabs were much more abundant during June-August 1985 than during the same period in 1984. Mean monthly densities on the bar during June-August 1985 ranged from 153 to 2251 crabs/hectare and during June-August 1984 ranged from 6 to 96 crabs/hectare. As densities of Size Class I crabs increased on the bar during late spring and summer, there was no corresponding increase in densities upstream from the bar. In the estuary upstream from the bar, densities of Size Class I crabs were generally highest during late fall and winter.

The 0+ age crabs, which began to enter the estuary by early May, entered as early instars or as megalops larvae that metamorphosed to first instar juveniles. Many early instars remained on the bar during spring and summer (Table 2). During 1985, when 0+ age crabs were more abundant on the bar than in 1984, densities of early instars were greater on the north end of the bar. Densities of 0+ age crabs on the bar generally decreased by early fall.

Densities of Size Classes II, III, and IV were typically low on the bar (Table 2). In the area upstream from the bar, densities of Size Classes II and III were usually higher than densities on the bar. Densities for these two size classes (upstream from the bar) were high in fall 1983 and summer and early fall 1985; these high densities were largely due to high catches in Baker Bay (Stations 3 and 6). In the estuary upstream from the bar, densities of Size Class IV crabs were lower than those of Size Class II and III crabs.

Bottom salinities and temperatures varied spatially and temporally during the study (McCabe *et al.* 1986). Results from simple and multiple regression indicated that bottom salinity and temperature, both individually and together, were poor predictors of crab densities for all size classes combined and for individual size classes. In no case was more than 24 percent of the variation explained by salinity or temperature.

Discussion

During late spring and summer there was a distinct pattern in the densities of 0+ age crabs in the estuary. Densities of early instar crabs were relatively high on the bar, yet subtidal areas upstream from the bar and intertidal areas of Baker Bay generally had much lower densities. In Grays Harbor estuary, which is located about 80 km north of the Columbia River estuary, Stevens and Armstrong (1984) estimated that intertidal areas with extensive eelgrass beds (*Zostera marina* and *Z. noltii*) had densities of 1-5 early instars/m^2. They found early instars buried just below the surface and in *Callianassa* spp. burrows. In a later study, Armstrong and Gunderson (1985) reported that densities of early instars in eelgrass in Grays harbor were 7/m^2 in May and 2/m^2 in July. Densities of early instars in shell debris were even greater than those in eelgrass; they reported densities as high as 115/m^2 in May. Apparently the intertidal areas of Baker Bay, which are composed of mud and fine sand, do not provide suitable habitat for early instar Dungeness crabs; extensive eelgrass beds and large amounts of shell debris are not found in Baker Bay. Although we examined only two intertidal sites in Baker Bay and did not examine the substrate as thoroughly as did the researchers working in Grays Harbor estuary, we feel that if 0+ age crabs were intensively using the intertidal areas, catches of early instar crabs in subtidal areas of the bay would have been much higher. Furthermore, during a 1-year benthic study (1980-81), which included monthly sampling along an intertidal and subtidal transect in northwestern Baker Bay, Furota collected only one Dungeness crab (T. Furota, Faculty of Science, Miyama 2-2-1, Funabashi, Chiba 274, Japan, pers. comm.).

Our observations in the Columbia River estuary were similar to those made in Grays Harbor estuary by Stevens and Armstrong (1984), who noted widely fluctuating crab densities (all size classes combined) at individual stations; however, periods of relative abundance differed between the two estuaries. Stevens and Armstrong observed greatest densities during May to August, with lowest densities in October and November. Only one station sampled by them in October-November had >200 crabs/hectare. In the Columbia River estuary, densities were also high at some stations during late spring and summer (Figures 2, 3), particularly the bar stations in 1985; however, unlike Grays Harbor estuary, densities of crabs in the October-November

period were relatively high at some stations. For example, the highest crab density in our study (18,194 crabs/hectare) was observed in Baker Bay (Station 6) in October 1985. The primary value of the comparisons is to indicate seasonal differences in relative densities within each estuary, since annual crab populations can fluctuate widely (Gotshall 1978, Tasto 1983); it is important to note that the Grays Harbor study and our study were done in different years.

Densities of Size Class II (50-99 mm) and III (100-129 mm) crabs were particularly high at Stations 3 and 6 in Baker Bay during summer and fall. These shallow channels, which are lower water velocity areas, probably provide excellent feeding areas for crabs. Dungeness crabs consume fish and benthic invertebrates, such as amphipods, clams, isopods, and shrimp (Gotshall 1977, Stevens *et al.* 1982). Durkin and Emmett (1980) found that benthic invertebrate densities in Baker Bay were highest in June, September, and December, and lowest in March. During our study, the shrimp *Crangon franciscorum* was frequently observed in the trawl with Dungeness crabs. In Grays Harbor estuary, Washington, *Crangon* spp. were important in the diet of Dungeness crabs with a mean width of about 80 mm (Stevens *et al.* 1982). Fishes are also abundant in the shallow channel areas in Baker Bay during summer and fall (Bottom *et al.* 1984, Fox *et al.* 1984).

Most of the increase in crab densities at Station 10 during the second year was probably due to the relocation of the station. Station 10 (second year) apparently provides good habitat for crabs, particularly for crabs <100 mm in carapace width.

In November-December 1984, crab densities at Station 6 were extremely low in comparison to fall 1983 (Figure 3). The lower densities in November 1984 may have resulted in part from hopper dredging operations that began prior to November sampling. In the absence of hopper dredging, densities at Station 6 might still have been lower than during fall 1983; however, the decline might not have been as great. Crab densities at the other Baker Bay site (Station 3), which was not dredged during fall 1984, were also lower in fall 1984 than during the preceding fall. Crabs at Station 6 could have been affected both directly and indirectly by dredging activities through entrainment, reduction of food supply, and loss of suitable habitat. Hoeman and Armstrong (in Armstrong *et al.* 1982) observed that when Dungeness crab densities were high in Grays Harbor estuary, dredge entrainment rates were correspondingly high. They estimated that the mortality rate for entrained crabs exceeded 70 percent.

Other stations in the estuary were also in or near areas that were dredged during the 2-year study: Stations 1 (bar), 3 (Baker Bay), 10 (RKm 19-20—second year), and 24 (bar). Stations 2 and 25, which were located on the bar, may also have been influenced by hopper dredging. Most of the dredging on the bar was done during spring and summer 1984 and 1985. In 1984, the U.S. Army Corps of Engineers (COE) deepened the Columbia River entrance channel from 14.6 to 16.8 m (mean lower low water). The COE (1983) estimated that during the initial deepening 7.6 million m^3 of material would be removed from the entrance channel; annual maintenance dredging for the entrance channel was estimated to be 5.4 million m^3 of material. Catches at the above stations might have been greater in the absence of dredging. Timing of our sampling in relation to dredging is also an important factor. Catches were probably lower in an area that was dredged immediately prior to sampling than in an area that was dredged days earlier. In 1985, the hopper dredge entrained large numbers of 0+ age crabs when dredging the bar (K. Larson, U.S. Army Corps of Engineers, P.O. Box 2946, Portland, OR, pers. comm.).

In conclusion, although the Columbia River estuary is a river-dominated estuary with widely fluctuating salinities, subtidal areas provide valuable habitat for Dungeness crabs. Unlike in Grays Harbor estuary, Washington (a more saline estuary), 0+ age Dungeness crabs do not intensively utilize intertidal areas of the Columbia River estuary (Baker Bay).

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Wave Behavior in Plant Tissue

Abstract

Non-electromagnetic standing waves have been found in plants. Some characteristics of these waves such as velocity, antinode spacings, and frequencies have been determined. Proof for their existence consists of measured electrical patterns, recorded oscillations, and excitation behavior. These standing waves are here termed W-waves for their discovery in wood.

Introduction

During the winter of 1987-1988 while studying xylem anisotropy (Wagner 1981 and Wagner 1988a,b,c,d) a surprising observation was made. Sections of trunk of varying lengths were cut from near the bases of live small trees and from shrubs of several different species. Immediately after cutting, the trunk section was completely debarked and two probes were inserted. A fixed probe was placed about 3 mm from the cut at the bottom (base) of the dowel-like section as a reference and the second probe was used to measure voltages incrementally up the sample (Figure 1). Probing revealed two outstanding electrical features. First the probes showed that negative voltage peaks occurred at regular intervals of 7.6 cm. Second, the samples were usually highly negative between the ends (base and top of the trunk sections). The 7.6 cm spacing of voltage peaks slowly emerged within a few minutes following insertion of the probes. The upper probe sometimes recorded what seemed to be a pulse reflected back and forth in the fresh sample of tree or shrub. Here was surprising evidence of a standing wave building up which reminded one of a resonating organ pipe. The shorter trunk sections tested seemed to show the greatest contrast between voltage lows and highs with the peak voltages higher. This occurred in all species tested: mountain lilac (*Ceanothus integerrimio*), willow (*Salix* sp.), California black oak (*Quercus kellogii*), Douglas-fir (*Pseudotsuga menziesii*), hazelnut (*Corylus* sp.), madrone (*Arbutus menziesii*), and ponderosa pine (*Pinus ponderosa*). Slowly the periodically distributed charge disappeared beginning at the bottom of the tree or shrub section. The top of the sample often became highly charged (approx. 250 mv) and then finally the charge disappeared. After these tantalizing first results from freshly cut tree sections, the present study was undertaken to characterize in more detail the wave patterns observed in trees and other plants *in situ.*

Standing Waves

Standing waves arise from the superposition of wave trains traveling in opposite directions. Two wave trains traveling in opposite directions interact at some points to produce constructive (antinodes) and at other points to produce destructive (nodes) interferences. The results are the stationary peaks and valleys of a standing wave pattern. Standing waves can be produced in a string or rope tied to rigid supports, in an open or closed pipe, in a radio antenna or transmission line, in crystals, and so on. Reflection of a traveling wave from boundaries is generally what produces the waves traveling in opposite directions. For example, reflection of sound from a boundary such as the end of an organ pipe produces a wave traveling in the opposite direction in the pipe. When the waves reflect back and forth inside the pipe they interact to produce the familiar standing wave pattern. See, for example, Halliday and Resnick (1970: 313-316) or other introductory physics text for further discussion.

Materials and Methods

Compared to surface probes, penetrating electrodes proved more reliable. Most of the penetrating probes were made of #16 nickel plated steel pins, etched in dilute nitric acid. The etching removed the nickel and reduced the probe resistance to near 100k ohms (calculated by using loaded and unloaded voltages) which can be as high as 500k ohms with smooth steel. Probing, on debarked surfaces, was done quickly on cold (near 2°C) high humidity mornings to prevent drying.

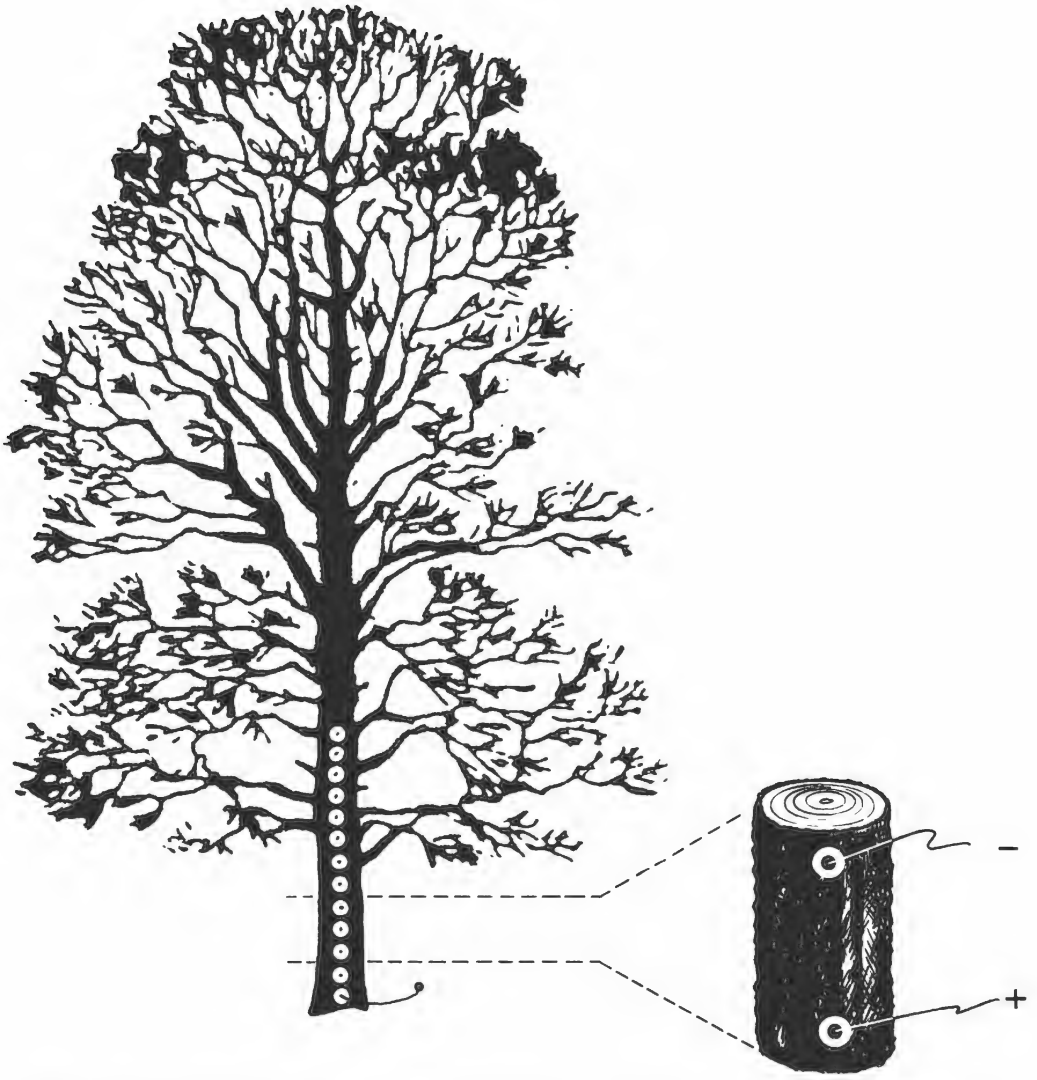

Figure 1. This is a schematic of a tree with contacts in place and of a cut section. The reference probes are at the bottom of the tree and the section diagram. The polarity placed on the section is representative of the polarity obtained when standing waves were first observed on cut sections.

Two methods of placing probes were used. One method, the two probe method, involved inserting one electrode near the base of the tree, the reference probe, and the other further up. The multielectrode method involved inserting several electrodes along the tree above the reference probe (Figure 1). Spacings between electrodes were 2.5 cm. (1.0 in.). The bark was cleared by hand from a 0.64 cm diameter area using a wood drill bit from which the centering screw was removed. Care was taken not to damage the underlying xylem. The electrode was pushed about 4 mm into the exposed xylem. The basic patterns were still observed in trees not debarked but these patterns were not so well defined. A 1.3 cm (0.5 in.) electrode spacing was considered but to

prevent excessive tree damage a 2.5 cm (1.0 in.) spacing was used instead. (Measuring along tree trunks was done with a measuring tape calibrated in inches.) When inserting electrodes attempts were made to avoid branches. The sequential probes in series were kept in line as much as possible as they went up the tree. This may not have been necessary since early data revealed, especially in the small diameter cases, that maximum voltage areas circled cut sections and tree trunks. Differences in composition and placement of probes possibly produced some scatter in the data but not enough to obscure the wave pattern.

A Keithley Instrument millivoltmeter (169) was used to take readings from probes on trees and other samples. Its input impedance was 11 megohms so if the probe resistance happened to be as high as 500k ohms the maximum voltage error would have been less than 5 percent. Separate battery operated (DC) supplies were used to power the strip chart recorder and the offset adjustable amplifiers. Coaxial cable, common mode cancellation with differential amplifiers, and grounding were used where possible to minimize unwanted signals. Checks were continuously made to find and eliminate stray electrical signals.

Pattern measurements were taken daily between 900 hours to 1800 hours during the first month. Later the data were taken about twice a week. In the beginning, hundreds of sequential probes were placed on a madrone, a ponderosa pine, and other trees and readings taken. From initial tests it was found that a one meter row of probes (electrodes) was usually sufficient to detect standing waves. Pine and fir tend to coat electrodes with pitch so probe resistance needs periodic checking. If the probe resistance became too high the electrodes were moved.

Since much of the data deal with multiples of a specific length, units that emphasize this length are utilized as needed (i.e. p = 7.6 cm. (3.0 in.).

A zero crossing is a point where a wave pattern crosses the zero polarity (determined by the reference electrode) axis. Since the zero crossing location depends on where along in the total wave pattern the reference electrode is placed one cannot always easily determine ahead of time what the end-to-end polarity of a cut section will be.

Pulse velocity

To determine the velocity of the wave trains producing the stationary standing wave patterns, "damage" pusles were utilized. For measuring "damage pulse" velocities, one electrode was pushed into the tree at 0.3 m and a second at 1.8 m above the ground. Then either chopping at the base of the tree with an ax or driving in a nail was usually sufficient to produce a traveling disturbance (pulse) in the wave pattern that apparently moved up the tree, was reflected from the tree top, and then traveled down to the bottom (Figure 3). A Houston Instrument high impedance input 2 channel strip chart recorder was used to record damage pulses. Since the DC output from the probes on a tree can be more than 400 mv two offset adjustable high input impedance amplifiers with an approximate gain of one were built so that the chart recorder could be centered on the 20 mv scale. Frequencies from the strip chart recorder data were determined by counting the number of cycles per unit time. The base diameters of trees examined ranged from 9 cm to 54 cm. The trees tested were so large and the instruments and displacement used to produce a damage pulse could be so small that it is unlikely that a sonic effect produced the damage curve.

To relate the damage pulses to the wave patterns a nail was driven in successively up a tree and recordings made from two probes in place. (Douglas-fir 8.8 m with 10 cm base dia.; 11 March 1988 for figure 4). Starting at the base of the tree, a #8d nail was driven in (approx. 0.6 cm.), pulled and then driven in again, successively up the tree at p/3 intervals. This was done 42 times. At each nail location a damage curve was recorded on the strip chart recorder from the two electrodes in place on the tree. The maximum voltage displacement of each curve was plotted versus distance up the tree (Figure 4).

Results

Standing Waves

Initially the two probe method at p/6 intervals failed to show periodicity clearly although there was a low level pattern. This method showed large patterns, however, with zero crossings several meters apart (or with only one crossing at the base of the tree) on the debarked trunks of red alder (*Alnus rubra*) and willow (late February 1988). Not until multiple probes were placed at p/6 and p/3 intervals did shorter wavelength repeating patterns show clearly with high stability (Figure 2).

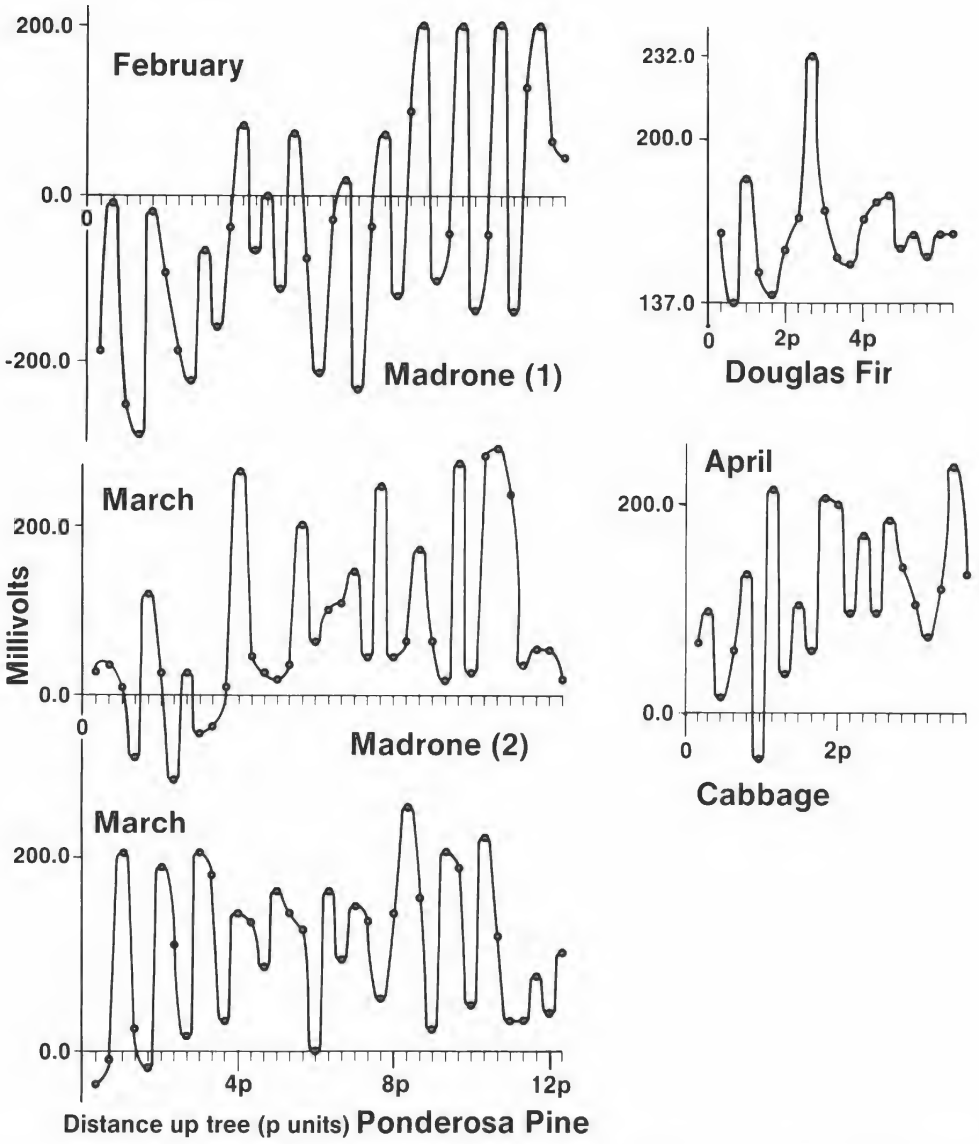

Figure 2. Wave patterns from four different plants (trees except for cabbage). These patterns were obtained from plotting voltages, taken from equally spaced probes, versus distance up the named species. Note that all the maximum voltages lie in the 200-300 mv. range. The probe spacing was p/3 except for cabbage where it was p/6 where p = 7.6 cm. The lowest probe (indicated by 0) was used for the voltage reference. The madrone 1 and madrone 2 plots are from the same tree and the same probes with a month between readings. See the text.

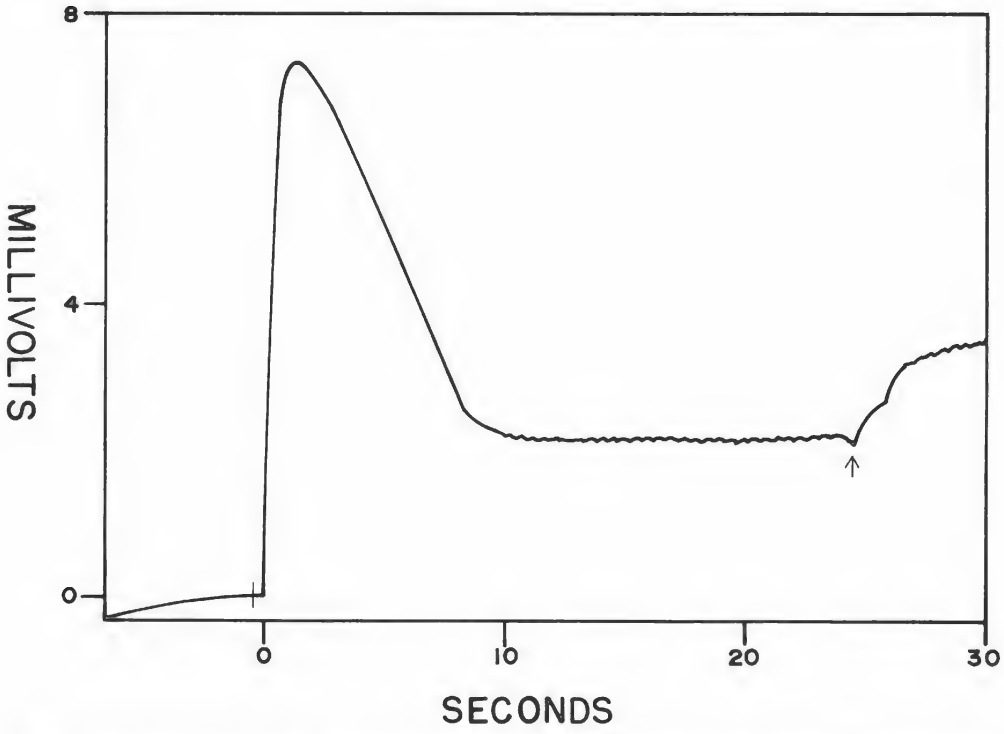

Figure 3. After centering the strip chart recorder this is the output from two Douglas-fir probes before and after a chop with an ax to the base of the tree. The two probes were placed at 0.3 m and 1.8 m from the ground. The 0 seconds is the time the pulse passed the lower probe on its way up after the chop. The line crossing the curve just to the left of zero represents the approximate time of the chop. The arrow points to the reflection blip.

Included in Figure 2 are short sections of patterns from madrone, Douglas-fir, ponderosa pine, and cabbage (*Brassica* sp.). First, notice how the madrone patterns (i.e. 1 & 2 Figure 2; using the same probes on the same tree) changed from February 28 (1) to March 25 (2). This was a very gradual change from day to day. The February peaks in the March pattern have shifted, and/or have changed amplitude, or merged. The predominant spacing is p in the February pattern while the March pattern shows the spacing between the main peaks to have a tendency to favor a 2p spacing. Referring to the ponderosa pine pattern (March 25 data), the main peaks were still spaced at near p as they were in February (not shown). The pine apparently had not yet broken dormancy but the madrone showed signs of some leaf growth. In cabbage (unpeeled) the probes were spaced at p/6. The graph shows an average spacing of 3.4 cm between peaks (April 9 data). The last probe lay in a fast growing region of the cabbage stalk which may explain the larger spacing between the last two peaks of the graph.

Searching for a zero crossing on a 10.5 m Douglas-fir provided the short pattern from probes centered 8.5 m high. The reference probe was at the base of the tree. Since there was no structure less than 137 mv the reference line was placed at +137 mv instead of zero as a convenience in plotting. The predominant spacing here was close to 2p. The modes involving p and 2p are easier to see but the patterns indicate that other modes are present because their structure is more complex than pure sine.

Pulse Velocity

For pulse velocity measurements we chopped into the base of the tree. The curve of Figure 3

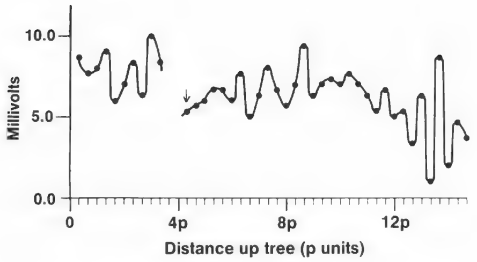

Figure 4. The wave type pattern (coming from 2 probes) resulting from driving in a nail successively up a tree. The nail was driven in at p/3 spaced intervals going up the tree where p = 7.6 cm. The nail that was driven in was lined up with the two electrodes in the tree. This necessitated skipping the electrode at location #12. Recall that there are electrodes at 0.3 m (location #12) and at 1.8 m. Also #11 was skipped due to proximity to #12. Hitting the nail at location #13 apparently caused the curve displacement downward due to the mechanical interaction with the probe at #12 but the approximate periodicity still continued. The arrow indicates location #13. Locations #11 and #12 are in the break.

represents the output due to a chop on an 8.8 m Douglas-fir. This curve is designated a damage curve. The first tall peak is a direct response to the chop. Notice the small downward inflection in the curve at approximately 25 seconds indicated by the arrow. This is a reflection blip. Usually there is some positive drift all along the damage curve but the relatively large positive drift after the reflection blip here (Figure 3) is somewhat unusual. So far only shorter trees (6.0-11.0 m) have clearly produced reflection blips. Larger trees have produced delayed oscillations but no definite reflection blips so far.

Driving a nail in a tree 42 times successively up the tree produced another standing wave type pattern with near p periodicity (Figure 4). This oscillatory response to excitation seems to indicate the presence of standing waves in the tree.

Discussion

In initial tests, the trunk samples were taken near the base of trees or shrubs because this area was relatively free of branches. These samples usually had a negative polarity. If they had been taken from other portions of the tree the polarity would likely have been positive. This perhaps is due to long wavelength patterns in trees which make regions alternate in polarity as one probes up a tree. Patterns like this were found in later winter tests on alder and willow as mentioned earlier. Perhaps when a short tree section is cut out, a long wavelength pattern furnishes the energy for the build up of the small pattern (7.6 cm) mentioned in the introduction.

The tree patterns (Figure 2) apparently are the result of the action of standing waves that distribute charges to the probed locations. A good analogy might be a Kundt's tube (Halliday and Resnick, 1970: 340) where acoustical standing waves in a pipe produce a pattern in cork dust or filings along the standing wave. Strictly speaking the pattern is evidence of the standing wave, but not the standing wave itself. (Most standing waves are detectable only from their effects.) The tree patterns observed from the probes apparently are analogous. They are produced by and provide evidence for the underlying standing waves.

Apparently electromagnetic waves do not produce the patterns because the apparent wave velocity is very small and a tree does not provide a very suitable medium because it is electrically conductive. However, this makes it difficult to monitor the various frequencies directly. As yet we have not developed a good transducer. The waves, however, pile up charge and thus voltages can be measured. The magnitude of fast changing voltages is small. It apparently takes time to build up charge sufficient to indicate a voltage as large as in the case of the a tree pattern where voltages are often hundreds of millivolts. Frequently small amplitude oscillations, usually less than one millivolt, were observed on the strip chart recorder when data were taken at 2.5 cm/hr and 25 cm/min (Table 1). (The lowest frequency oscillations listed in the table, however, had amplitudes of tens of millivolts apparently because there was time to build up charge). The observation of oscillations, especially with frequencies like 3.0 and 5.7 Hz, which are near calculated pattern frequencies, tends to confirm the presence of standing waves in plants.

Reflection calculations

Initially it was found that the delay between a chop and a "reflection blip" was approximately proportional to the tree height. This suggested reflection. Using the delay time and twice the tree height several tentative velocities were calculated. One also needed to take into account the probe

TABLE 1. Oscillation frequencies that have been measured coming from probes on trees. Only frequencies less than or equal to 5.7 Hz have been found so far. Two observed frequencies (3.0 and 5.7 Hz) were found to agree very closely with frequencies calculated from antinode spacings and a measured velocity. See further details in the text.

Frequency Observed	Associated Phenomenon	Date Temp	Comments
3.0 Hz.	Damage pulse	3/11/88 14.4°C	Ponderosa Pine 2p pattern
0.013 Hz.	Recent probes	2/17/88 6°C	2 hr. sampling madrone
0.01 Hz.	Recent probes	8/4/87 16°C	1 hr. sampling Douglas fir
0.005 Hz.	Recent probes	7/2/81 27°C	0.8 hr. sampling oak
Many low pulses	Recent disturbance	Anytime	Growing and dormant
0.53 Hz.	Ringing after damage	3/17/88 23°C	Ponderosa pine
0.0025 & 0.0027 Hz.	Possibly stomata behavior	7/87 approx. 30°C	Hot PM; oak; higher frequency superimposed on low
5.7 Hz.	Recent probes	3/31/88 21.1°C	Ponderosa Pine p pattern

locations. Further experimentation with the calculations, to produce the best agreement between velocities from trees of different heights, showed that one needed to consider the following three cases:

Case 1) A positive going blip. This was the most common response to an ax chop. This was hypothesized to be an indication of a reflected signal on its way down after reflection from the top of the tree. It was detected by the top of the two probes in the tree. Apparently there is no phase reversal when a pulse is reflected at or near the tree top.

Case 2) A negative going blip. It was hypothesized to be due to a pulse which missed the upper and the lower probes on the way down. The pulse was then apparently reflected from the base of the tree with a phase reversal and the upper probe detected the pulse as it passed. (In no case so far has it been reasoned that the lower probe detected a reflected pulse. Perhaps this is due to the wave pattern arrangement in the vicinity of the lower electrode and the base of the tree.)

Case 3) First a positive going blip and then a negative going blip. This seems to represent a combination of 1) and 2). This permits a second calculation of velocity with one chop, because one velocity can be obtained using case 1 and a second velocity calculated by using the time delay between the two blips and twice the height of the top contact. This helped confirm that a velocity was being measured since the two velocities were approximately the same. The two velocities obtained, however, usually differed from one another by several percent. The difference may be due to the ambiguity in the exact location of the bottom and top of a tree for reflection purposes. This type of response seemed to occur with a relatively high amplitude damage pulse.

If the curve in figure 3 is assumed to be a case 2 curve then a careful measurement from 0 seconds (the time the pulse passed the lower probe on its way up) to the point where the curve starts to bend downward (the time the reflected wave returns) gives an elapsed time of 23.9 seconds. The tree height was 8.8 m. Double the height and add 1.5 m for the distance from the tree base to the upper probe less the height of the lower probe; divide this sum by 23.9 seconds and the calculated velocity is 79.9 cm/second, the distance traveled divided by the elapsed time.

Measurement of several tree heights combined with the corresponding damage curve revealed initially that the pulse velocity was 90 ± 6 cm/sec. (5 Douglas-fir and madrone of various heights). Combining this velocity with the p spacing gives a calculated frequency of 5.9 Hz (the wavelength is twice the antinode spacing and frequency equals velocity divided by wavelength). Data taken a month later (19 April 1988) revealed a lower average velocity of 81 cm/sec (Douglas-fir) perhaps due to the effect of breaking dormancy.

Conclusions and Observations

Possibly the wave behavior described here is common to all plants. However the wave behavior is not restricted to live plants. Similar phenomena have been observed in sections of trees filled with salt solution (unpublished data). Salt solution-filled wood and live trees provide channels for movement of these waves but channels may not be necessary.

It is assumed that the wave phenomena discussed here are related to phenomena observed in *Mimosa pudica* and in carnivorous plants (Jacobson 1965, and Stuhlman *et al.* 1950). The wave velocities obtained, for example, seem to be similar to the velocities obtained for stimuli traveling in these plants.

The many futile attempts by other workers (e.g. Raber 1933) to obtain repeatable electrical data using electrodes in plants can perhaps be explained in terms of changing and shifting seasonal wave patterns (e.g. madrone in figure 1). A suggested name for the waves described herein is "W-waves" since they were first observed in wood samples.

Acknowledgments

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RESEARCH NEWS AND COMMENTS

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The Richey-Roberts Clovis Cache, East Wenatchee, Washington

About 11,000 years ago Clovis people—the early Americans who made fluted spear points and hunted the last of the Pleistocene megafauna—rested on the gentle sandy slope near the present Pangborn Memorial Airport, East Wenatchee, Washington. How many times or why they stopped here, we don't yet know. What they left, however, was discovered in May 1987, by workers installing sprinklers in an apple orchard. They found the single most important Paleoindian site yet unearthed in the Pacific Northwest.

The assemblage contains decorated bone tools (wedges, foreshafts, pressure flakers?); stone artifacts included fleshers(?), bifaces, preforms and seven fluted lanceolate points. The huge fluted points (to 9 inches long) incited imaginative speculation about their "ceremonial" function(s). More importantly, however, part of this Clovis "cache" remains buried beneath the apple trees. These artifacts could be the first—of only four such Clovis caches known—to be seen *in situ* by archaeologists with the knowledge to decipher their significance.

At the request of the orchard owners, I agreed to direct a week-long excavation to determine the extent and importance of the site and, if possible, to remove the temptation for vandalism. With start-up support from Washington State University Graduate School and the Washington State Historic Preservation Office, a team of experienced volunteer scientists converged on the site. Some had intimate knowledge of the archaeology and past environments of the Northwest and Washington's Mid-Columbia region, whereas others had broad expertise in the Paleoindian period. We found many more *in situ* artifacts but removed only five stone artifacts for specific studies. Because the find became too important to investigate further without more time, financial backing, and detailed planning, we back-filled the excavated squares, placed concrete slabs over the site, and postponed excavations until the summer of 1989 (see *National Geographic Magazine* October 1988, p. 500).

The Richey-Roberts Clovis Cache is unique in the large number and size of its fluted points. More importantly, these artifacts are in place; their age and context will surely be known. This site has unparalleled potential for revealing the lifeways of the ancient mammoth hunters of the Pacific Northwest and something of their beliefs as well. We don't yet know what it all means, but, never before in the Pacific Northwest have such Paleoindian artifacts remained relatively undisturbed with ample time to plan for careful excavations incorporating exhaustive analyses.

With support from the National Geographic Society, I am presently working toward a minimal understanding of the stratigraphic, chronological, and technological context of the site, and its artifacts in order to plan and complete appropriate excavations in the summer of 1989.

Figure 1. Clovis points recovered from the Richey-Roberts Clovis Cache, Washington.

Dr. David H. Wagner, Chairman
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All members are encouraged to submit names for open positions in the Association and for honorary awards. Nomination for President-Elect, Treasurer, and five Trustee positions should be mailed by 15 February 1989 to:

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Tentative Schedule of Future Meeting Sites (corrected)

1990—Oregon State University, Corvallis
1991—Boise State University, Boise
1992—Western Washington University, Bellingham
1993—Eastern Oregon University, La Grande
1994—under negotiation

Meetings of Interest

Range Weed Short Course (24-26 January 1989).

The annual Range Short Course, sponsored by the Cooperative Extension Services of Idaho, Oregon, and Washington, will be held January 24-26, 1989 at the Ridpath Hotel, Spokane, Washington. Invited papers will address the invasion, biology, and management of cheatgrass as the introduced annual that now occupies much of our poor to fair condition rangeland. Knapweeds, leafy spurge, and rush skeletonweed will be presented as examples of introduced biennial or perennial weeds that replace cheatgrass as the frequently disturbed communities of exotics show no sign of yielding to native perennials in secondary succession. The proceedings will be published by Washington State University Cooperative Extension. Registration information is available through Ben F. Roché, Jr., Department of Natural Resource Sciences, Washington State University, Pullman, Washington 99164-6410.

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